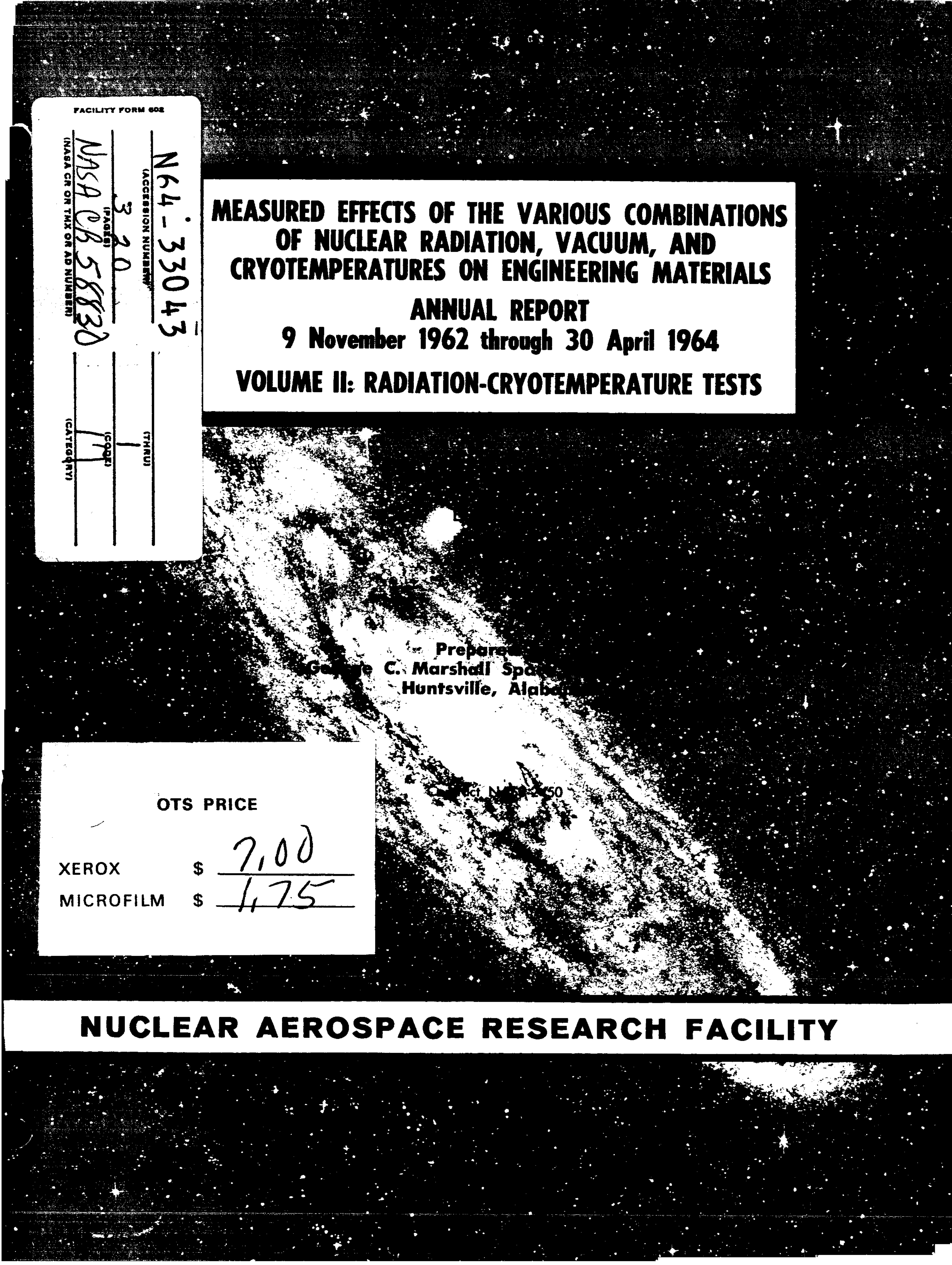

MEASURED EFFECTS OF THE VARIOUS COMBINATIONS OF NUCLEAR RADIATION, VACUUM, AND CRYOTEMPERATURES ON ENGINEERING MATERIALS

ANNUAL REPORT
9 November 1962 through 30 April 1964

VOLUME II: RADIATION-CRYOTEMPERATURE TESTS

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NUCLEAR AEROSPACE RESEARCH FACILITY

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NUCLEAR AEROSPACE RESEARCH FACILITY

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VOLUME II: RADIATION-CRYOTEMPERATURE TESTS

E. E. Kerlin
E. T. Smith

Prepared for
George C. Marshall Space Flight Center
Huntsville, Alabama

Contract NAS8-2450

GENERAL DYNAMICS | FORT WORTH

This report was prepared by General Dynamics/Fort Worth under Contract No. NAS8-2450, Measured Effects of the Various Combinations of Nuclear Radiation, Vacuum, and Cryotemperatures on Engineering Materials, for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Propulsion and Vehicle Engineering Division, Engineering Materials Branch of the George C. Marshall Space Flight Center, with Raymond L. Gause acting as project manager.

ABSTRACT

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A series of tests was performed to measure the combined effects of nuclear radiation and cryotemperatures on a group of nonmetallic spacecraft materials. This group consisted of materials classified as adhesives, seals, thermal insulations, electrical insulations, structural laminates, potting compounds, sealants, and dielectrics. Typical tests performed on specimens prepared from the materials included tensile-shear strength, leakage, ultimate tensile strength, ultimate elongation, stress-strain characteristics, thermal conductivity, pull-out strength of potted wire, and T-peel strength. Special test equipment allowed the specimens to remain submerged in liquid nitrogen during irradiation and subsequently to be tested without interruption of the cryogenic environment.

Measured properties of the materials as a function of integrated neutron flux and gamma dose are reported and recommendations for use of the various materials in applications associated with the test environments are made.

Author

REPORT SUMMARY

Research in the field of radiation effects has shown that drastic changes are effected in various engineering properties of nonmetallic materials by incident nuclear radiation. The successful use of nuclear reactors in space vehicles, either as a major source of propulsion or as a source of auxiliary power, will therefore depend, to a large extent, upon determination of the radiation resistance of component materials in the vehicle. The amount of fast-neutron and gamma radiation that a component can withstand and still function adequately varies not only from one material to the next, but with such environmental conditions as high vacuum, cryotemperature, or the combination of these two.

The purpose of this particular experimental program is to measure the effects of the combination environments of nuclear radiation and ambient air and of nuclear radiation and cryotemperature on the engineering properties of selected nonmetallic materials and to correlate the effects of these environments with different levels of radiation dose. The materials selected for testing in this program are representative of those most likely to be used in nuclear-powered spacecraft. During this second year's work, these materials consisted of two from each of the categories of adhesives, seals, structural laminates, potting compounds, and sealants; three from the categories of thermal insulations and electrical insulations; and one from the category

of dielectrics. Representative tests included those sufficient to measure the ultimate tensile strength, ultimate elongation, stress-strain in tension, tensile shear strength, thermal conductivity, pull-out strength of potted wire, and T-peel strength. The radiation source for the experiment was the Ground Test Reactor (GTR) located at the Nuclear Aerospace Research Facility (NARF) of General Dynamics/Fort Worth.

The procedure for the cryotemperature tensile tests was to position the test specimens in the cryogen chamber of the experimental assembly and locate the assembly next to the face of the reactor core. The irradiation was carried out with the specimens submerged in liquid nitrogen (LN_2). Operation of the reactor was terminated after the required radiation dose was achieved, and the specimens were pulled in tension while still submerged in cryogen.

For the ambient-air irradiation, tensile specimens were tied to expanded-metal racks and positioned next to the face of the reactor core in a framework open to the atmosphere. Subsequent tensile tests were carried out with an Instron machine in the Irradiated Materials Laboratory (IML).

Thermal-conductivity measurements were made on thermal insulation materials at ambient-air and LN_2 temperatures before irradiation and on specimens at LN_2 temperature after irradiation at LN_2 temperature.

For each tensile specimen, six data points were recorded during each test on each material. These included those obtainable from all combinations of three radiation doses - zero, relatively low [$\sim 10^9$ ergs/gm(C)], and relatively high [$\sim 10^{10}$ ergs/gm(C)]- and two temperatures - ambient-air and -320°F. Because of difficulties encountered with test equipment, tests originally scheduled to be conducted with liquid hydrogen were postponed until a later date.

A brief resume of the results of the tests on each material, along with tentative recommendations for its usefulness in applications associated with the pertinent test environments, is shown in the "results" portion, Section VI, of this report.

FOREWORD

NASA contract NAS 8-2450 was initiated 9 November 1961. Under this contract, the Nuclear Aerospace Research Facility of General Dynamics/Fort Worth is investigating the effects on selected non-metallic materials of environmental factors likely to be encountered by nuclear-powered spacecraft. The work is being performed specifically for the Propulsion and Vehicle Engineering Division, Engineering Materials Branch, of the George C. Marshall Space Flight Center, Huntsville, Alabama.

The report on the first year of work (9 November 1961 to 8 November 1962) appears in two volumes as GD/FW Report FZK-161-1 and -2. In the first volume, results of tests on materials irradiated in vacuum are reported; in the second, results of tests on materials irradiated at cryotemperatures are reported.

The work performed during the second year under the contract is reported in GD/FW Reports FZK-188-1 and FZK-188-2. The first volume deals with the effects of radiation on materials in a vacuum, both at ambient temperature and at cryotemperature. The second volume (this report) concerns the effects of radiation on materials at cryotemperature.

The authors wish to acknowledge the valuable services of the following people at NARF who have helped make these tests possible: Dr. R. P. Lightfoot for material selection and specimen preparation; F. F. Fleming for nuclear radiation measurements; E. E. Baggett and D. C. Butson for assistance in equipment design; R. E. Miller for design and operation of the electronic test instrumentation; J. E. Warwick for operation of vacuum systems; C. E. Morgan for design and operation of a bearing lubricant test; G. D. Martin for data analysis; and J. B. Wattier for statistical analysis.

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I. INTRODUCTION

Considerable effort has been expended in the past several years toward measuring the effects, individually, of nuclear radiation and of cryotemperatures on various classes of materials, particularly those materials which have been used in or have potential application to space vehicles. Up until the present NASA program at NARF, very little data had been accumulated that showed the combined effects of these two environmental factors. This was due, in part at least, to the difficulty of designing and fabricating equipment suitable for performing tests under these extreme conditions.

The annual report of the second year's effort on the program is presented in two volumes. Volume I (Ref. 1) presents data on the effect of radiation on materials while in an environment of air, vacuum, or vacuum and cryotemperature. Volume II, reported here, covers the effects of radiation on materials while in an environment of air or liquid nitrogen. The distribution list at the end of this report lists the facilities that received the two reports.

The vacuum report (Ref. 1) deals with the results of tests on 50 materials suitable for spacecraft service. These materials were selected from the application categories of adhesives, seals, thermal insulations, electric insulations, dielectrics, structural laminates, potting compounds, and lubricants. Some materials were tested in vacuum before removal from the vacuum-irradiation environment, but most materials were tested in air after irradiation in vacuum or air. All application categories but lubricants were tested in the cryogenic test program and are reported here. Sealants were also tested.

During the first year of these experiments (1962), part of the test program was designed to provide radiation effects data on 12 materials while in air, liquid nitrogen, or liquid hydrogen. These tests were performed on six different classes of materials - adhesives, seals, thermal insulation, electrical insulations, structural laminates, and thermal-control coatings (Ref. 2). The second part of the program was designed to provide radiation-effects data on 47 materials while in either vacuum or air during irradiation (Ref. 3).

The selection of specific materials for this program was based on considerations involving the past history of their use in spacecraft, potential use in this application, and knowledge of their properties after separate exposure to radiation and cryotemperatures. Measurements included tensile-shear strength, ultimate tensile strength, ultimate elongation, stress-strain characteristics, leakage, thermal conductivity, pull-out strength of potted wire, and T-peel strength. Tests for each tensile specimen were performed under six different conditions consisting of the possible combinations of three radiation doses (zero, relatively low, and relatively high) and two temperatures (ambient-air and $-320^{o}F$).

In the low-temperature portions of the experiment, the specimens not only were irradiated while submerged in LN_2, but were tensile-tested while still submerged in the LN_2. This factor in the experiment should be emphasized. It points to the fact that any annealing-out of radiation-induced defects resulting from warmup to room temperature prior to testing was eliminated, thus providing a measurement of the true conditions that exist in materials that have been exposed to and are to be used in this combination environment.

II. RADIATION FACILITY

2.1 Radiation Source

The radiation source used in these tests was the Ground Test Reactor (GTR), a heterogeneous, highly enriched, thermal, reactor utilizing water as neutron moderator and reflector, as radiation shielding, and as coolant (Ref. 4). Maximum power generation is 3 Mw.

The irradiation pool, shown in Figure 2.1, is divided into two sections.* The reactor is located in the water-filled south section, and the components to be irradiated are located in the dry north section. The reactor closet in the center of the pool divider extends into the irradiation cell to provide three sides for irradiation. The corresponding irradiation positions - east, west and north - are clearly visible in Figure 2.1. In this figure, the reactor is in the fully retracted position on the horizontal positioning mechanism. This mechanism enables the reactor to be positioned at any distance from 2 to 90 in. from the north face of the closet and will traverse the reactor the full 88-in. distance in 1 min, giving an effective source termination time of 10 sec.

The reactor closet is constructed of 1-in. aluminum plate and is partially covered by 1/4-in.-thick boral to attenuate

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*The GTR facility has been modified since the tests reported in this document were performed. For details, see <u>NARF Facilities Handbook</u>, GD/FW Report FZK-185 (March 1964).

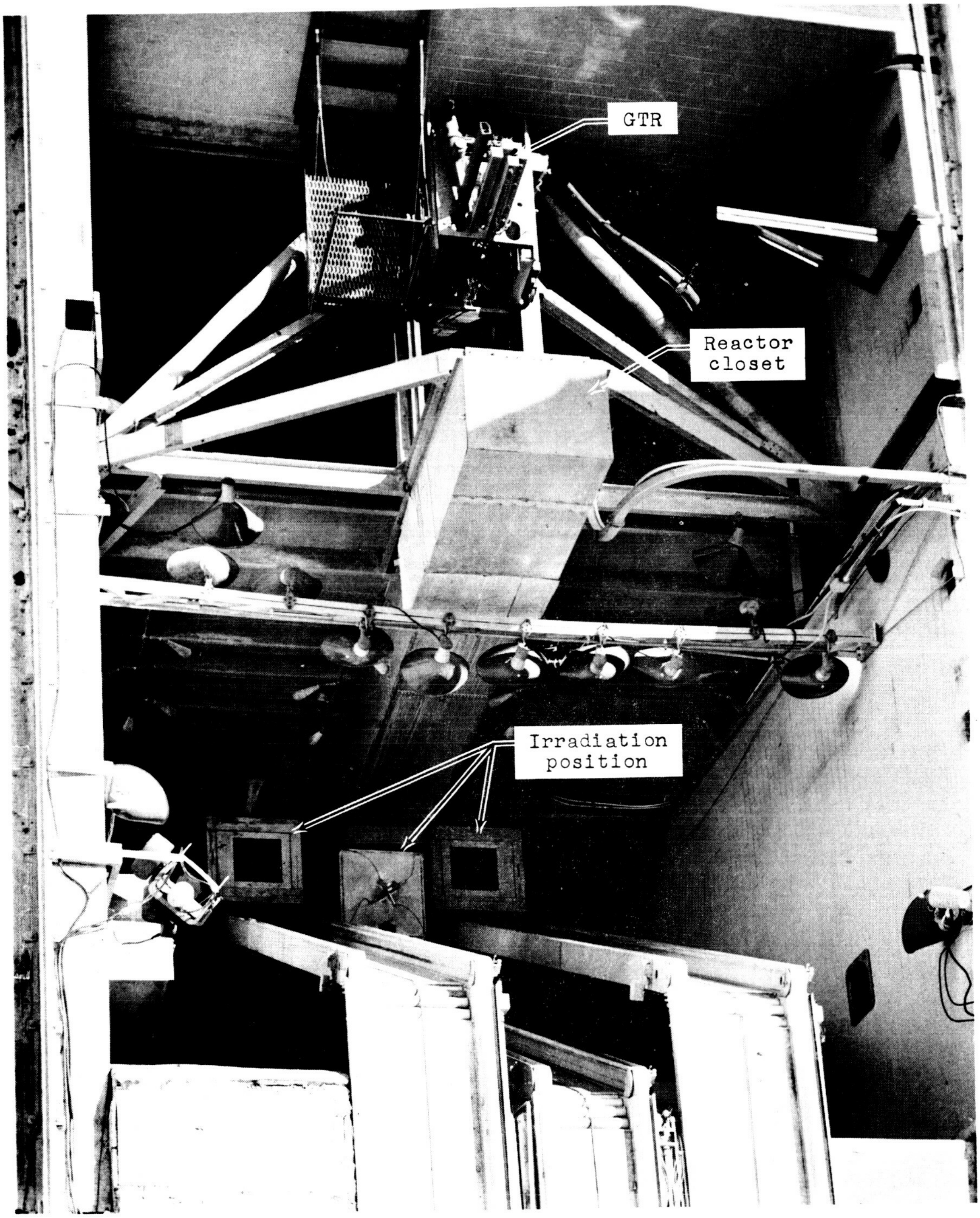

Figure 2.1 Reactor Pool

thermal neutrons. The boral extends 36 in. east and west along the pool divider from the closet and 36 in. up and down from the horizontal centerline of the reactor. The centerline is 57 in. above the cell floor.

The neutron spectrum (Ref. 5) of the GTR in a water moderator has been measured to be Maxwellian at thermal energies ($E < 0.48$ ev), approximately proportional to E^{-1} from about 0.5 ev to 0.1 Mev, and essentially a fission spectrum for higher energies. The shape of the neutron spectrum has been mathematically altered to account for the attenuation of the thermal flux by the boral surrounding the reactor in the dry-pool configuration. The resulting spectrum has been shown to represent the actual spectrum quite accurately (see Fig. 5.1 in Section V).

Flux measurements have been made in the thermal-, epithermal-, and fast-neutron energy ranges by use of a variety of thermal, resonance, and threshold detectors. Fast-neutron flux measurements ($E > 2.9$ Mev) made on the dry side of the reactor closet with the boral in place agree well with those made on the wet (or reactor) side. The measured thermal flux is in general agreement with that obtained by integration of the analytical curve (Fig. 5.1).

2.2 Radiation Effects Test Facility

Adjacent to the north wall of the irradiation cell is the handling area. Equipment permanently installed in the handling area includes a gas-monitoring system, a Davis explosion meter, and environmental conditioning equipment for the Radiation Effects Testing System. Figure 2.2 is a view looking south.

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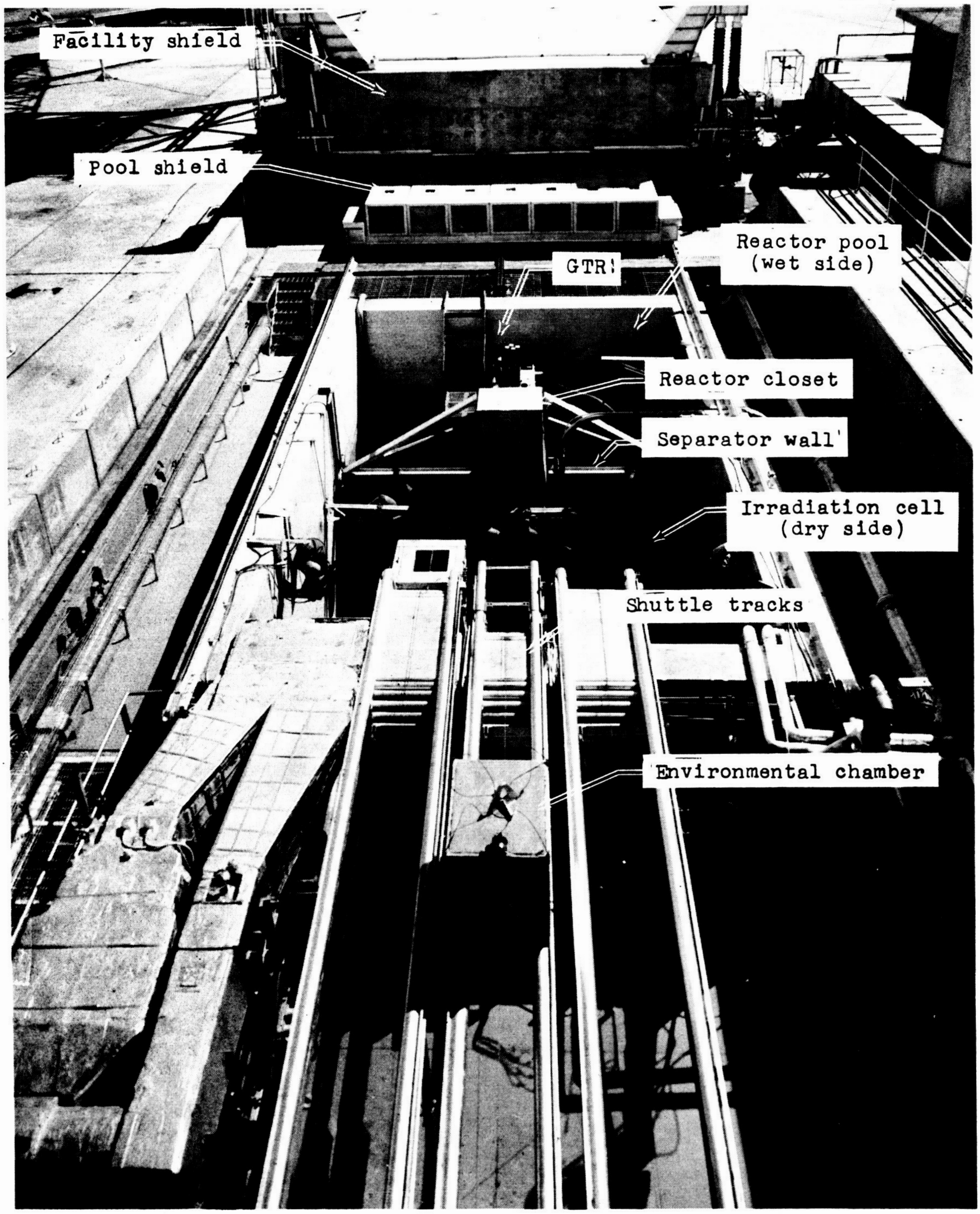

Figure 2.2 Radiation Effects Testing System

It shows the concrete pool shields, the irradiation pool, the shuttle system, and the handling area.

An integral part of the NARF Radiation Effects Testing Facility is the shuttle system, which is used to move items to be irradiated into position next to the reactor closet. This system consists of cable-driven dollies mounted on three sets of parallel tracks. The tracks extend from the irradiation positions adjacent to the closet, up an incline to the north wall of the irradiation cell, and to a loading area on the ramp just north of the handling area. The system can be operated from either the control room or the dolly motor-drive shed on the north ramp. Full-coverage televiewing of the entire shuttle system is provided by means of a closed-circuit television system in the control room.

III. TEST EQUIPMENT AND PROCEDURES

Evaluating the effects of various combinations of radiation, air, and liquid nitrogen on engineering materials requires the use of special techniques and equipment. In this section, a general description of the equipment and procedures used in this test program is given. For a more detailed description, the reader is referred to the first annual progress report published under this contract (Ref. 2).

3.1 Ambient-Air Static Test

Specimens used in the ambient-air irradiation test were wired to expanded-metal trays and the trays installed in slots of an aluminum box frame like that shown in Figure 3.1. The box frame, in turn, was fastened to one of the shuttle-system dollies and positioned next to the reactor face.

Specimens scheduled to receive the same radiation dose were wired to a tray in a circular pattern. This arrangement was necessary because of the essentially circular pattern of isodose lines that exists in planes out from and parallel to the reactor face during irradiation. Different doses were obtained by placing the specimen trays at predetermined distances from the reactor face.

At the completion of the ambient-air irradiation period, the trays were removed and delivered to the Irradiated Materials Laboratory (IML), where they were stored until the specimen radioactivity had decayed to a level safe for handling and testing by

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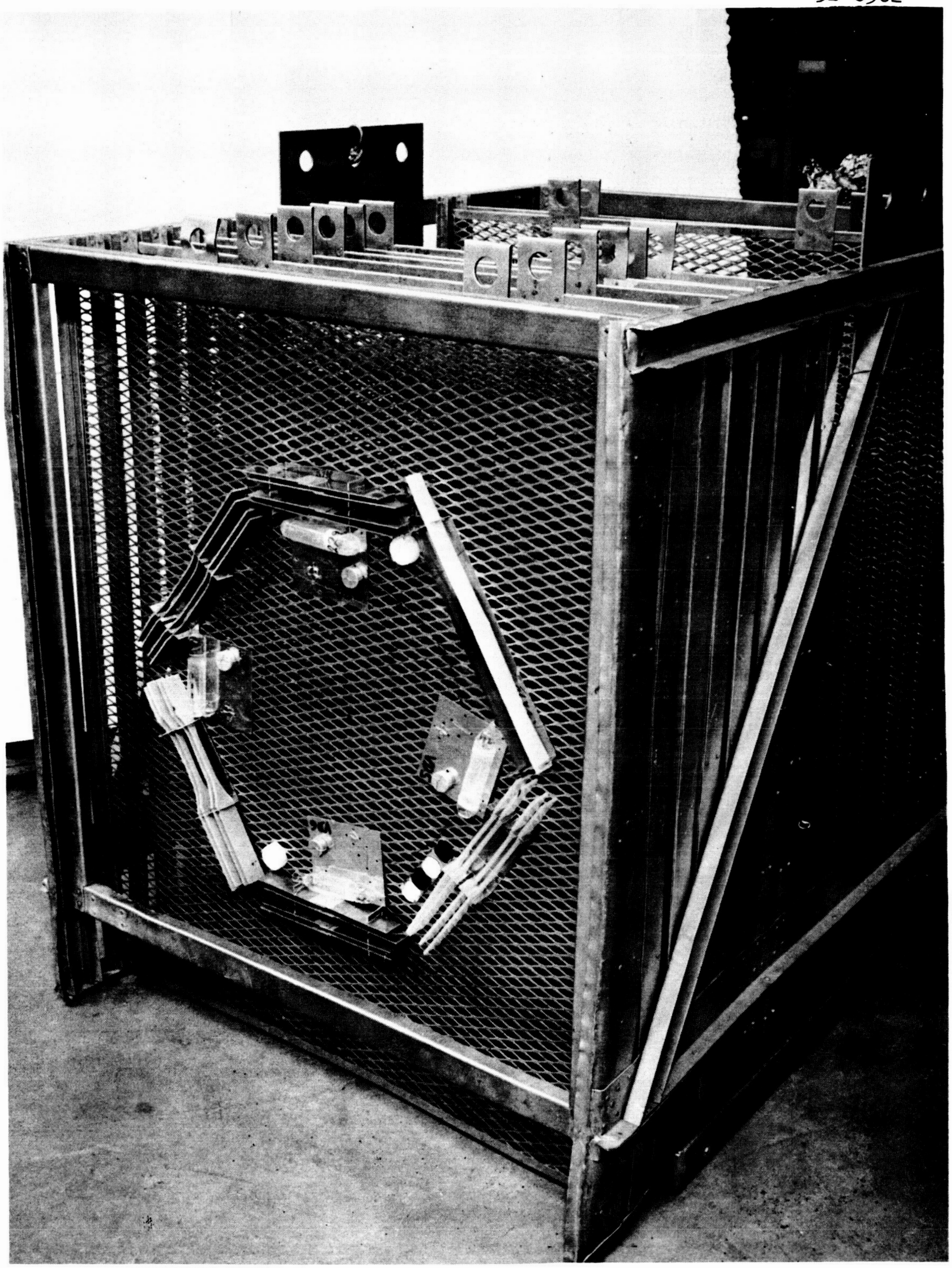


Figure 3.1 Static Samples on Rack for Ambient Irradiation

hand. The specimens were then removed from the trays and tested at room temperature in a Model TT Instron machine.

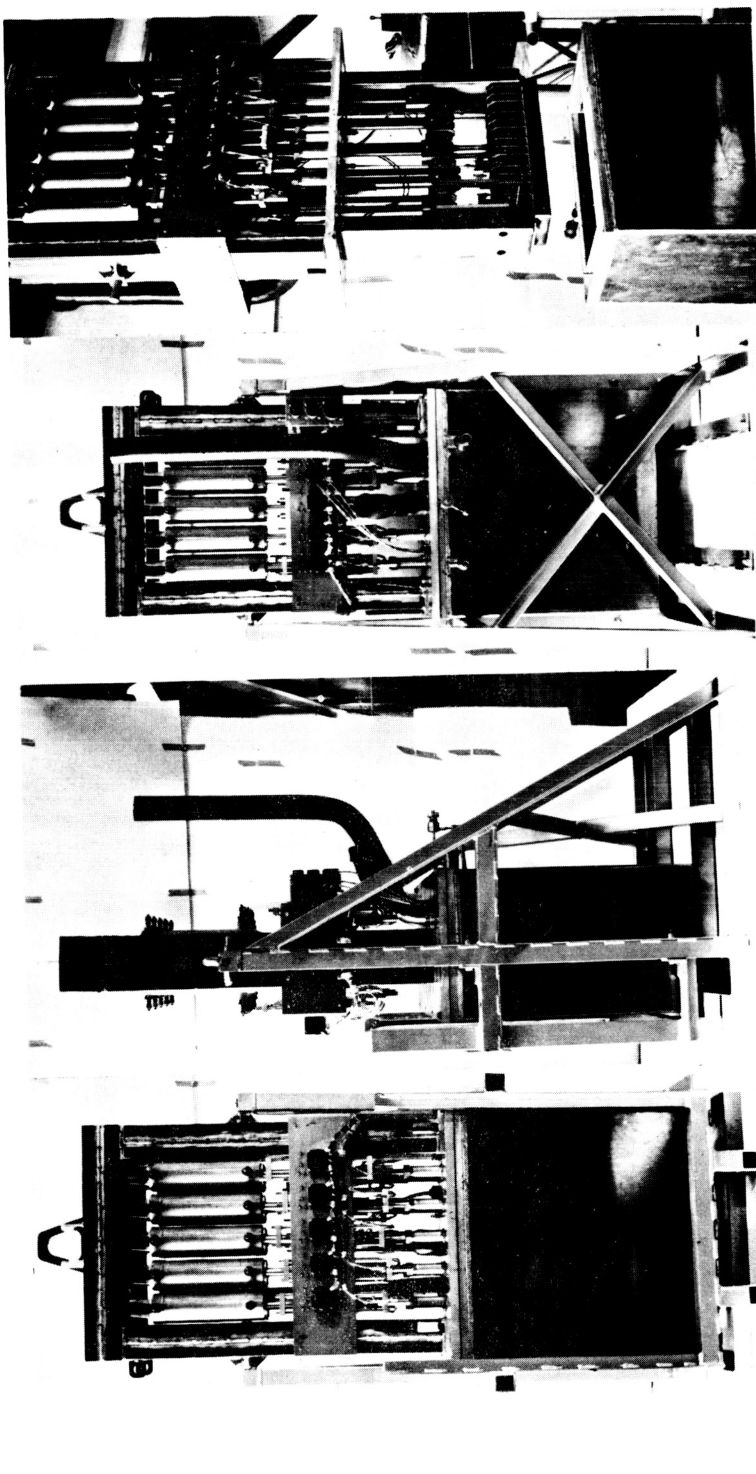
Ambient-air control and ambient-air irradiated specimens of the dumbbell, lap-shear, T-peel, and wire-pull type were tensile-tested in the Instron machine. Two clevises of the same type as those used to mount specimens on the pull rods in the experimental assemblies were installed in the Instron to ensure specimen loading conditions duplicating those in the experimental assemblies. The pull rates used in testing the different ambient-air specimens in the Instron agreed closely with those shown in the appropriate ASTM specification.

3.2 Cryogenic Test

3.2.1 Experimental Assembly

The assembly used for testing materials at cryotemperatures in a nuclear-radiation field is shown in Figure 3.2. The photograph shows the front, side, and back of the complete assembly mounted in a support frame. During operation the support frame, with the experimental assembly installed, is fastened to a dolly on the shuttle system, which automatically positions it next to the face of the reactor.

Figure 3.2 also shows an exploded view of the assembly with the tensile-pulling section removed from the cryogen dewar. The tensile-pulling section consists of two main parts: (1) an upper structure containing ten hydraulic cylinders, a cylinder mounting frame, ten pull rods, ten linear variable differential transformers (LVDT's), and ten motors with corresponding LVDT



Front Side Back Separated

Figure 3.2 Various Views of Experimental Assembly coil traverse assemblies; and (2) a lower section containing the specimen-mounting structure and ten pull-rod clevises to hold the specimens. These two main sections are bolted to a common plate which serves as the cover for the dewar. This plate contains pull-rod risers wrapped in heater coils to prevent ice build-up on the pull rods, a cryogen inlet tube, evaporated-cryogen outlet pipe, pressure transducers, and holes for mounting the liquid-level probe and for passage of thermocouple leads. More detailed information on the assembly can be found in Reference 2.

The LVDT's were used to measure the movement of the pull rods to an accuracy of $\pm$ 0.001 in. over a range of 0.60 in. The LVDT core was mounted on the pull rod, and the LVDT coil was attached to a motor-driven traverse assembly which can reposition the coil over a 4-in. vertical range.

One of the experimental assemblies utilized five 0- to 1000-lb range dynamometers mounted in line with the pull rods. These dynamometers measured load on the specimens directly rather than indirectly through the hydraulic servo system and Instron testing machine.

3.2.2 Dewar

After completion of the 23 April 1963 irradiation, examination of the dewars revealed that small detonations had taken place during the test, causing the inner walls of the dewar to rupture (see Fig. 3.3). Reasons for the detonations, a description of a subsequent LN_2 investigation, and a discussion of the resulting changes to the dewar design are presented in Appendix D.

Figure 3.3 Experimental Assembly Dewar with Ruptured Inner Wall

During the course of repair of the ruptured dewar, the decision was made to conduct, during the next irradiation test, a parallel experiment to measure the effectiveness of cold nitrogen gas as an insulation against heat flow from the outer walls of the dewar to the LN_2. Vacuum insulation was eliminated. Instead, 1/4-in.-diam holes were drilled on 2-in. centers around the top edge of the cryogen chamber. Additional holes were drilled in the bottom of the outer vacuum-chamber wall. This arrangement allowed evaporated cryogen to flow into the vacuum chamber at the top, down around the sides of the cryogen chamber, out of the vacuum chamber and into the next chamber at the bottom, up the side of this chamber, and out to the atmosphere through a 1-in.-diam outlet port (see Fig. D-1 in Appendix D).

This method of insulating the dewar proved to be as effective as insulating with a vacuum, and it eliminated the maintenance necessary when using a vacuum. Consequently, all three NASA dewars were converted to this cold-gas-flow arrangement, and these modified dewars were used in subsequent liquid-nitrogen tests.

3.2.3 Accessory Equipment

A Model TT Instron machine was used to control piston movement in the hydraulic cylinders on the experimental assembly. A "master" hydraulic cylinder was connected to the crosshead of the Instron. This cylinder was connected by hydraulic lines through a selector panel to the experimental assembly "slave" hydraulic cylinder. Forces exerted by the Instron machine were thus transmitted indirectly to the specimens in the experimental assembly. During cryogenic control runs or irradiations, the Instron chart recorded, as a function of time, loads applied to the piston of the master cylinder. The actual load on the specimen was determined by subtracting the tare load (which consists of drag on the master-cylinder piston plus drag on the slave-cylinder piston and pull-rod risers) from the master-cylinder load.

A Model 150-1100 Sanborn Carrier Preamplifier was used in conjunction with a basic Model 150 Sanborn oscillograph to record on a chart the movement of the pull rod (LVDT output) as a function of time. For pull rods with dynamometers attached, another carrier preamplifier channel was used to record on a chart the dynamometer load as a function of time. In this case, the actual load on the specimen was determined by subtracting from the dynamometer load the drag load caused by the pull-rod-riser seal. The Instron and Sanborn charts were pipped simultaneously at intervals during the recording of data to provide time correlation.

The cryogen liquid level in the dewar was monitored by an instrument designed by NARF personnel for this purpose. The dewar liquid-level probe consisted of seven 1000-ohm carbon resistors installed at various intervals along the probe. Cryogen coming into contact with the resistors resulted in a large increase in resistance. This change in resistance triggered a light on the facility instrument panel corresponding to a particular liquid level. To control the cryogen level in the dewar, a thermocouple was installed in the probe at the point where the cryogen level was to be maintained. The output voltage from this thermocouple was fed into a Bristol Recorder which, in turn, pneumatically controlled the dewar supply valve on the cryogen-supply manifold. An increase in temperature above LN_2 temperature resulted in a corresponding increase in the valve opening.

The cryogen-chamber pressure was measured by a 25 psig potentiometer-type Colvin pressure transducer. The output from this transducer was recorded on a Westronics recorder.

Further information on all cryogenic experimental assembly accessory equipment can be obtained from Reference 2.

3.3 Thermal-Conductivity Test

This test involved measuring the thermal conductivity of various rigid, organic, foam-type thermal-insulation materials over a temperature range of from +90° to -290°F after exposure to a "relatively low" and a "relatively high" dose of nuclear radiation.

3.3.1 Basic Plan of Tester

A system of three concentric cylinders was used. The inner cylinder was made of copper and served as a cylindrical heat source. The middle cylinder was made of the insulation material (test specimen), and the outer cylinder was constructed of either copper or aluminum and served as a housing for the assembly. Figures 3.4 and 3.5 show the vertical and horizontal cross sections, respectively.

It is obvious from the geometry that the thermal conductivity k_{m_1} of the test specimen is much lower than the thermal conductivity k_{m_2} of the outer casing. Therefore, for the test con-

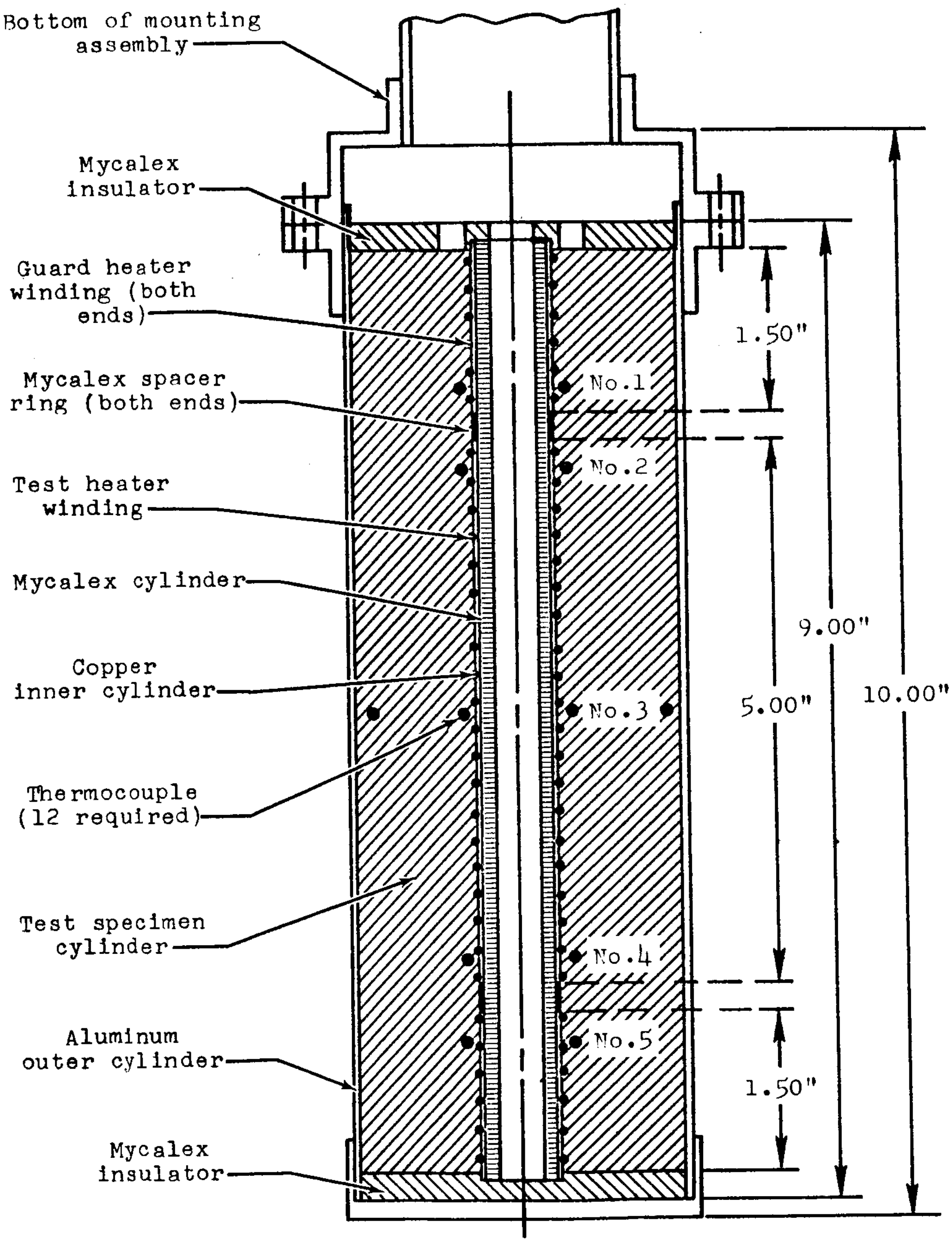


Figure 3.4 Thermal-Conductivity Tester: Vertical Cross-Section

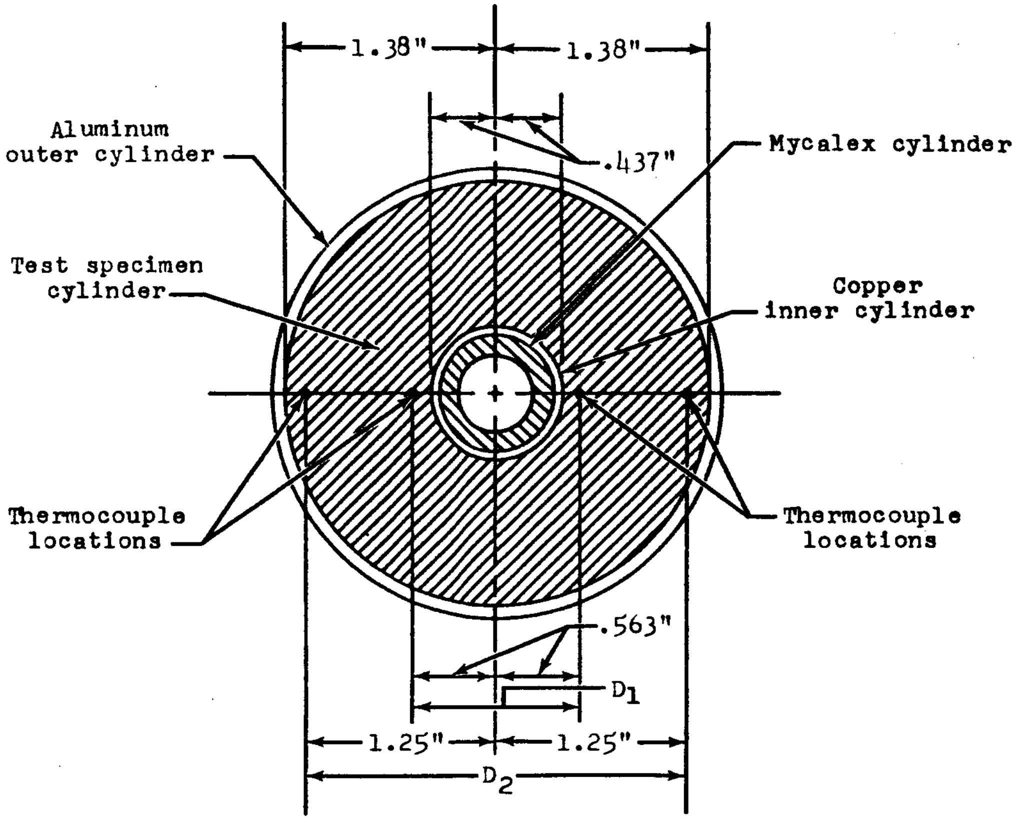


Figure 3.5 Thermal Conductivity Tester: Horizontal Cross Section

figuration used in this experiment,

$$k_{m_1} = \frac{q\left[\ln\left(D_2/D_1\right)\right]}{2\pi h\left(T_1-T_2\right)}$$

where T_1 and T_2 are the temperatures at D_1 and D_2, the inner and outer diameters (approximately) of the test specimen (see Fig. 3.5).

Validity of the above expression for k_{m_1} depends upon the complete expenditure of the heat generated by the test heater power, q, radially through the test specimen and over the total length, h, of the test heater. Figure 3.4 shows the "effective" length of the test specimen to be h and shows the location of the test heater as a coil of wire wrapped in grooves on the inner cylinder. The relatively small value of 5 in. for h requires a guard heater on each end of the assembly to ensure radial distribution of all the heat generated in the test heater.

Five pairs of thermocouples were used to obtain T_1. The thermocouples in each pair were mounted 180° from each other in a plane perpendicular to the longitudinal axis of the heaters. They were positioned 1/8 in. deep into the foam from the heaters (see Fig. 3.5). Pairs 2, 3, and 4 were used to record the inner temperature of the foam adjacent to the heater along the length h, and the six recorded temperatures were averaged to arrive at a mean value for T_1.

Pairs 1 and 5 were used to monitor the temperature of the foam adjacent to the end (or guard) heaters. Power to the guard heaters was varied during a data cycle to ensure that the average of temperatures recorded for thermocouples in pairs 1 and 5 matched, respectively, the average of those recorded for thermocouples in groups 2, 3, and 4. This assured the radial distribution of all energy generated by the test heater.

Two additional thermocouples in the same plane with pair 3 were used to determine temperature T_2 of the test specimen at a point 1/8 in. into the foam from the outer surface of the test cylinder (see Fig. 3.5). The two temperatures were averaged to obtain a mean value for T_2. As mentioned above, values of D_1 and D_2 are equal, respectively, to the distances between the thermocouples used to measure T_1 and those used to measure T_2. Three-mil thermocouple lead wire was used to minimize conduction losses from heat generated in the test heater for expenditure through the test-specimen foam.

The end insulators, cylindrical core for the heaters, and heater spacers were made from Mycalex, a glass-bonded mica. The heater wire was fiber-glass-covered constantan. This wire has a diameter of 0.003 in. and a resistance of 29 ohms/ft. Leads for the heaters were 20-gage stranded wire.

3.3.2 Original Thermal-Conductivity Tester

Two models of the thermal-conductivity tester were used in the test program. Some differences between these models were: (1) the outer cylinder construction, (2) the inner foam cylinder construction, (3) the method of thermocouple installation, and (4) the construction of the tester mounting assembly.

The prototype model used an outer cylinder made of copper. The procedure for assembling this model was to mount the test heaters, heater leads, Mycalex end pieces, thermocouples, and thermocouple leads into final configuration within the copper outer cylinder. Then the heater leads were carried out of the unit through the core of the Mycalex cylinder, and thermocouple leads were carried out through the center space where the test foam was to be located. After installation of all wiring and thermocouples in the unit, test specimens made from foam materials such as Stafoam AA-402, AA-602, and CPR-1021 were prepared by mixing the foam components, pouring them into the container, and allowing the mixture to foam to the top and solidify.

Approximately nine test units were foamed in this manner. This assembly method, however, produced several problems. Amounts of foam components sufficient to free-foam a volume slightly larger than the center cylinder were used. But with a container such as this, closed on nearly all sides, the resulting density of the foam after solidification was significantly greater than that which would be obtained by foaming in free-space. This, of course, prevented a strict comparison between published k-value data and data taken in these tests, because published data are mostly based on densities resulting from free-foam conditions.

Problems were also encountered after the test units were foamed, problems that were magnified by the impossibility of making changes or repairs within the unit after the foam was in place. For example, open circuits in heaters and thermocouples were discovered in several of the units after completion of the foaming operation, thus rendering the units useless for thermal-conductivity measurements. In these cases, no data were taken.

In some units where the number of open circuits was small (perhaps two or three thermocouples) the data were taken,but were subsequently judged as being unreliable.

Two of the units that were foamed successfully and appeared to provide reliable data during ambient test conditions produced data that varied widely at cryotemperatures. Accumulated evidence indicated that leaks were developing in the epoxy used to seal the top and bottom caps on the tester. When different sealing compounds were used, better integrity of the units was realized at cryotemperatures, but the use of these different compounds did not completely eliminate the problem. Figure 3.6 shows one of the prototype models that was cut in half, longitudinally, to permit viewing the internal construction of the unit and to judge the quality of the foamed-in-place test specimen.

3.3.3 Modified Thermal-Conductivity Tester

As a result of the problems described above, a second model of the thermal-conductivity tester was designed with corrective modifications. The outer cylinder and bottom and top caps were made of aluminum, primarily because of the short-half-life radioactivity of this material. The top cap was reconstructed with an integral flange suitable for mating to another flange attached to the outer cylinder. This permitted the cap to be bolted and sealed with an indium-wire gasket for a positive air-tight joint that could be disassembled and reassembled without difficulty. The bottom cap of the test unit was soldered to the outer cylinder.

Figure 3.7 shows a redesigned connecting tube used to join the test unit to the top plate of a dewar. This tube, made from

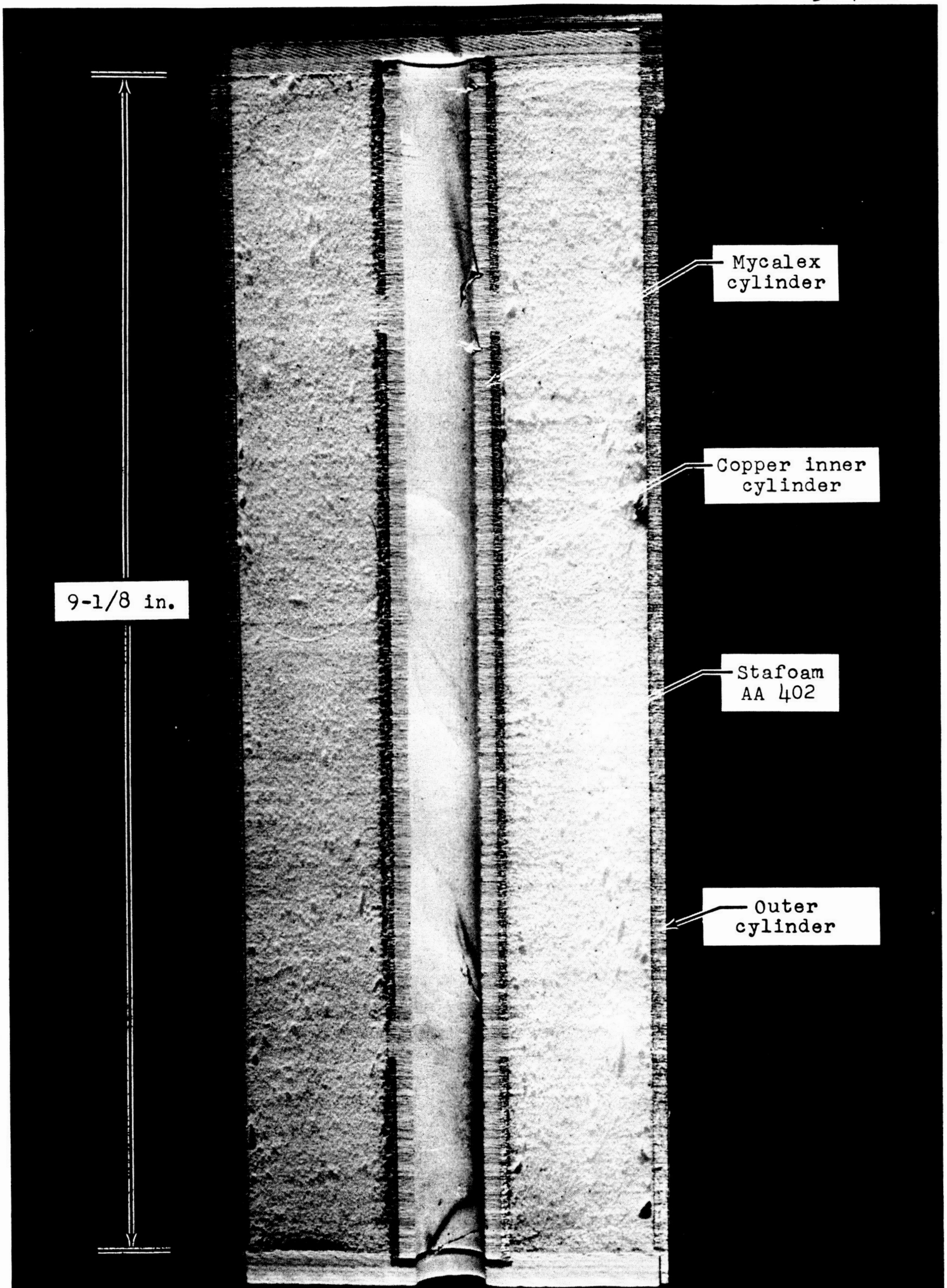


Figure 3.6 Thermal-Conductivity Tester: Vertical Cross-Sectional View

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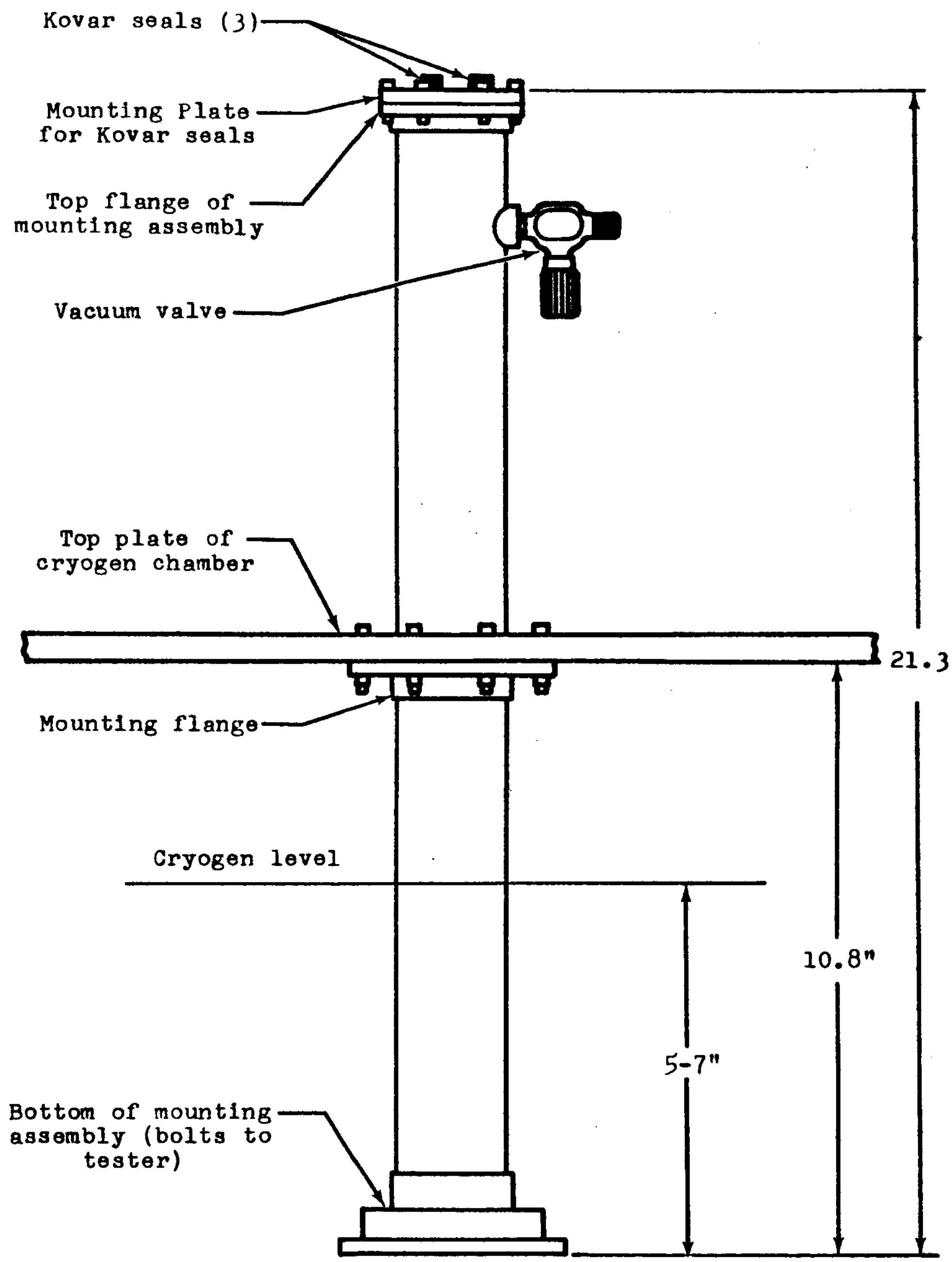

Figure 3.7 Mounting Assembly for Thermal-Conductivity Tester

aluminum, served to support the unit and to furnish a housing for heater and thermocouple leads. This assembly arrangement provided for a portion of the tube, along with the test unit, to be submerged in cryogen during low-temperature operation. The submerged portion of the tube furnished a radiation heat sink for the heat being conducted from outside the dewar, through the electrical leads toward the test assembly. All electrical leads from the test unit passed through Kovar seals at the top of this extension tube. The flange in which the Kovar seals were soldered in place was bolted to another flange soldered to the top of the tube and the joint sealed with an indium-wire gasket.

The sealing arrangements permitted a vacuum to be pulled on the connecting tube and the test unit whenever the unit was submerged in liquid nitrogen. This prevented the accumulation of condensate, ice, or liquid air in various openings and crevices that existed in the unit.

Another method of constructing the middle cylinder (test specimen) was devised in lieu of the foam-in-place operation. This involved machining blocks of foam into cylinders that could be inserted into the tester. Four foam cylinders were constructed in this manner, although the inner diameter of two of these was considered too large to allow proper contact with the test-heater cylinder. These latter two were used for trial and error experiments in installing thermocouples.

After some difficulty, thermocouples were installed successfully in one machined-foam cylinder of CPR-20-2 and one cylinder of CPR-1021-2 by means of a modified hypodermic needle. This method of assembly provided good contact between the thermocouple junction and the foam. The test heater core assembly was then inserted into the foam cylinder, the foam cylinder positioned into the outer cylinder, wiring connected, and the entire assembly mated and sealed.

This new approach to construction of the unit allowed repairs and alterations to be made more readily. Figures 3.4 and 3.5 show dimensions and basic details of the later model tester.

Figure 3.8 is a photograph of two of the assembled test units mounted to the top plate of the test dewar. Figure 3.9 is an exploded view of the unit and Figure 3.10 is a photograph of the instrumentation used in the experiment. Power was supplied to the heaters by a regulated dc power supply. The power could be varied manually. A Rubicon Potentiometer and/or Kintel amplifier plus a Non-Linear Systems Digital Voltmeter was used to measure the output of the thermocouples, and the heater power.

3.3.4 Test Procedure

The technique for making k-value measurement involved the gradual application of heat to the test and guard heaters until T_1 (measured by thermocouple pairs 2, 3, and 4) exceeded T_2 by 30° to 50°F. After a reasonable stabilization time for thermocouples in pairs 1 through 5, the temperatures were recorded and averaged and the average values for T_1 and T_2 substituted into the equation for k_{m_1} (Section 3.3.1). Corresponding values of q, in watts, were changed to Btu/hr and also substituted in the same equation.

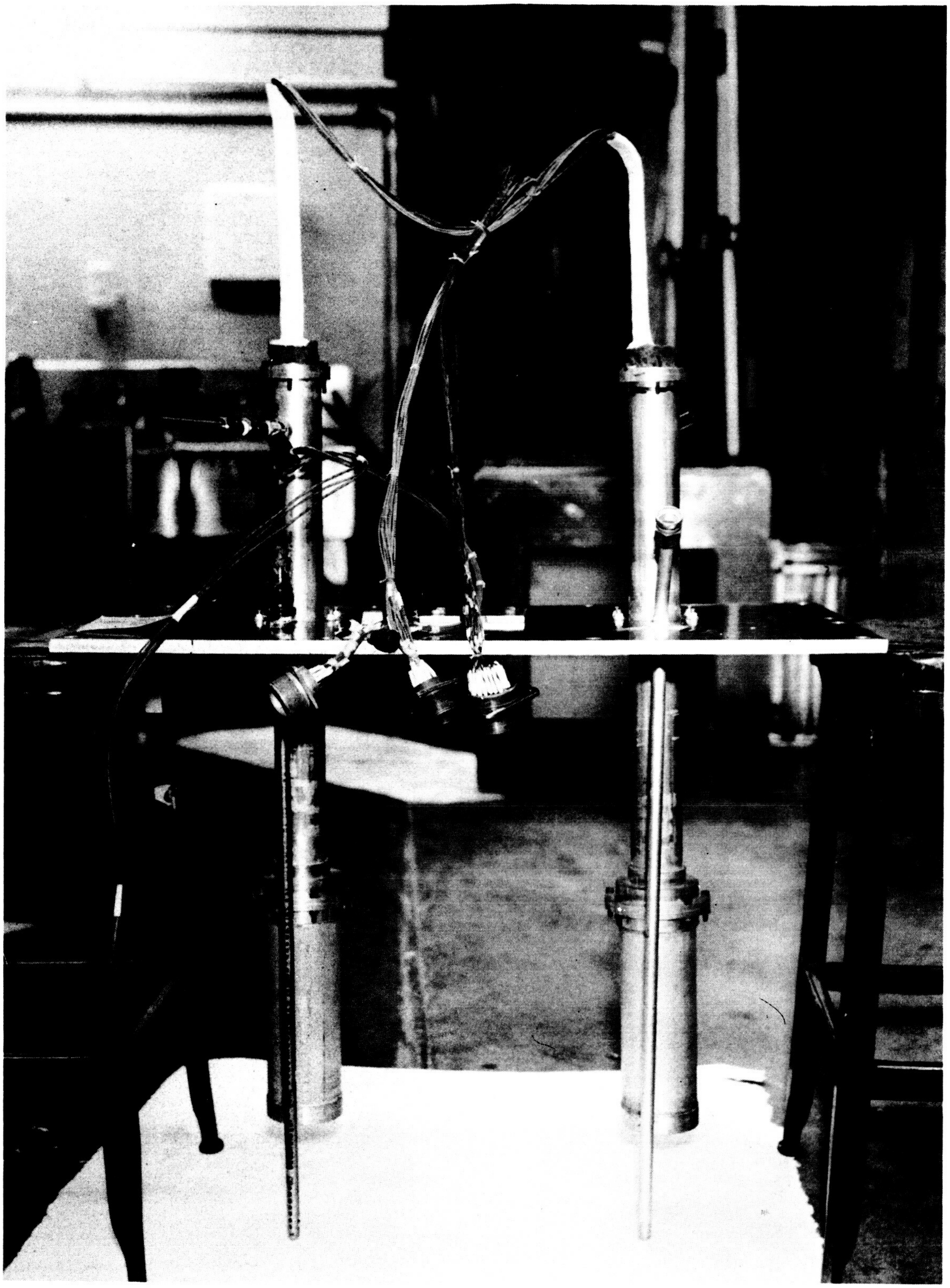

Figure 3.8 Thermal-Conductivity Tester: Irradiation Test Assembly Mounting

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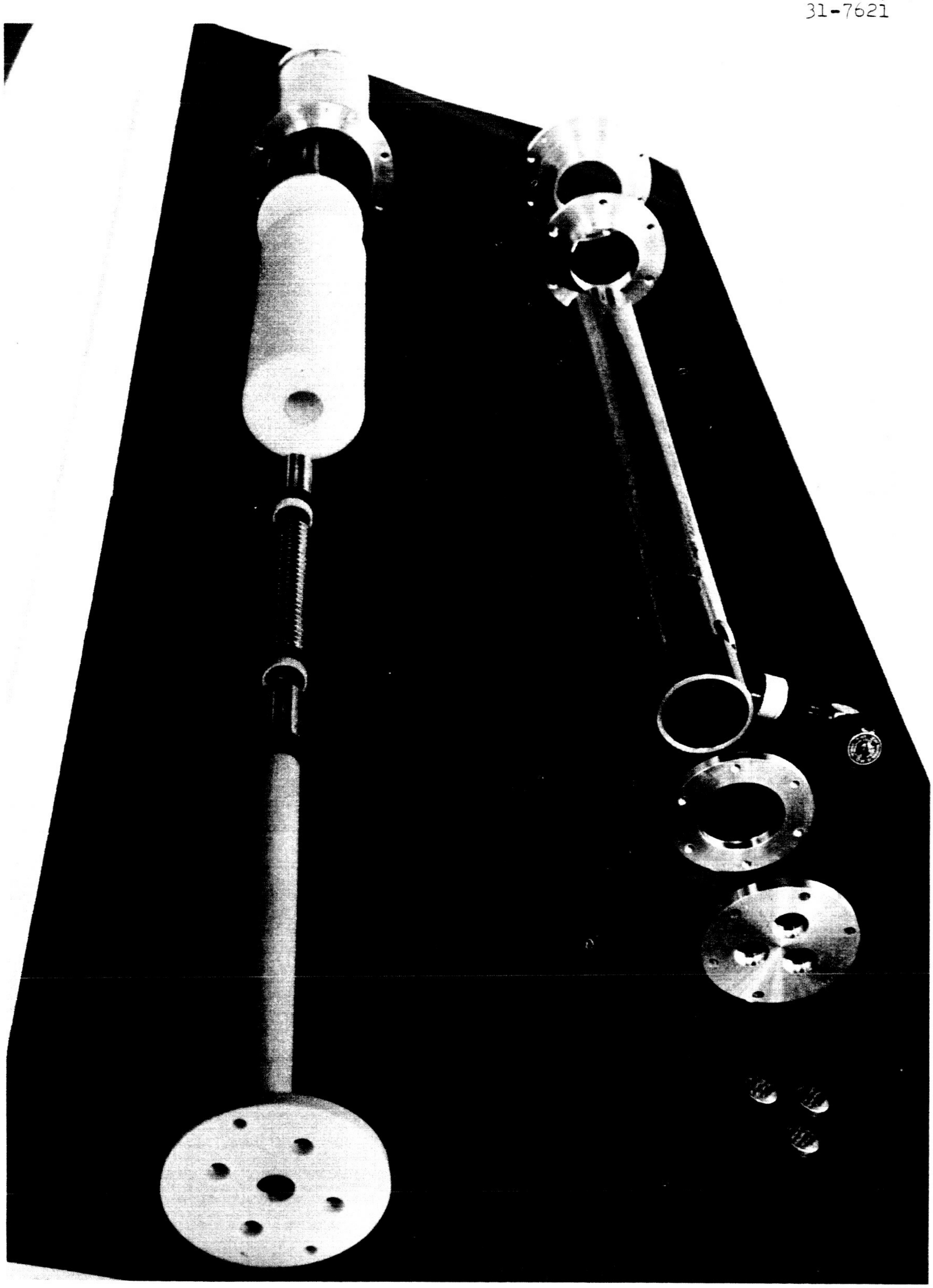


Figure 3.9 Thermal-Conductivity Tester: Exploded View

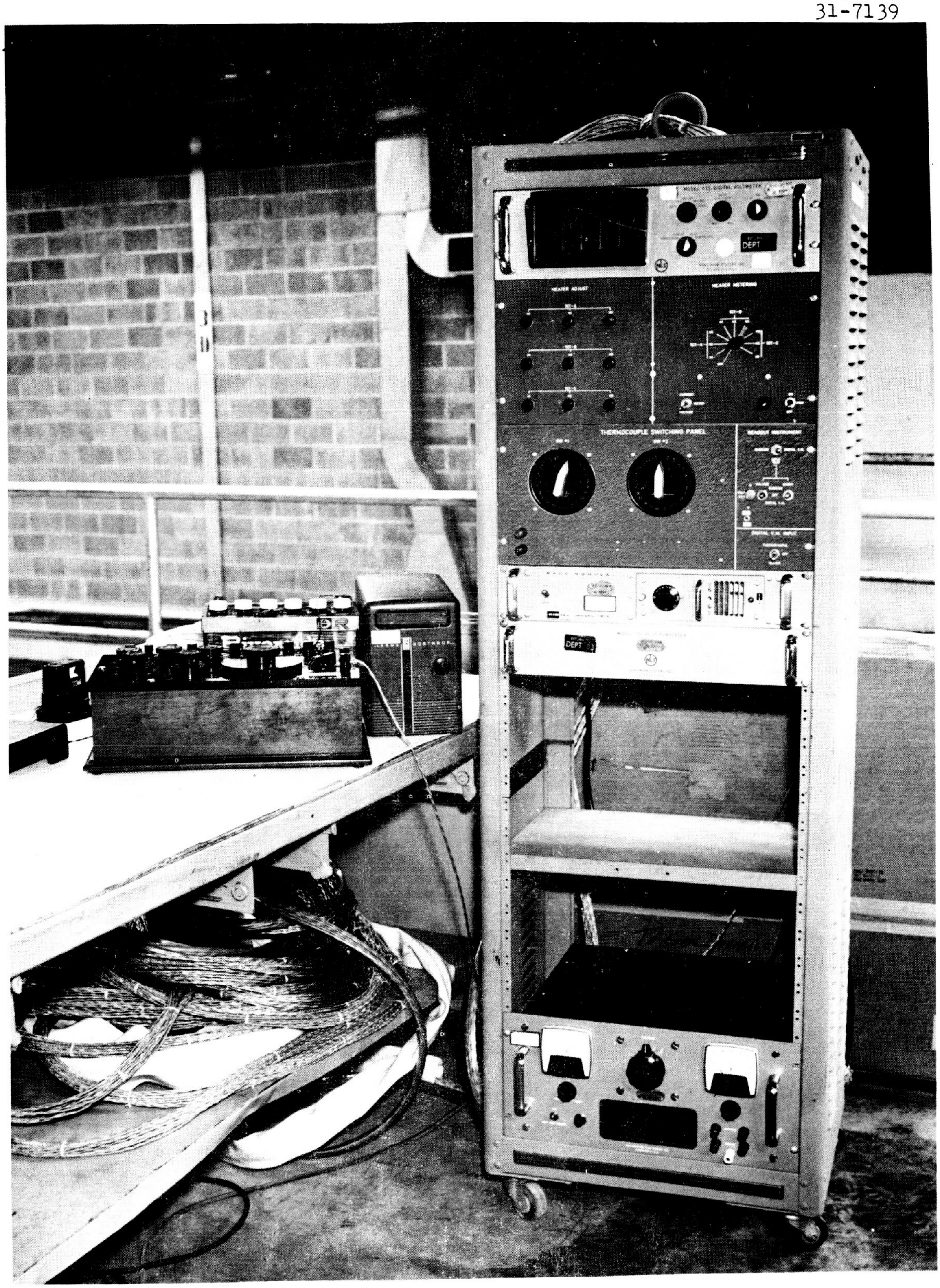


Figure 3.10 Instrumentation for Thermal Conductivity Test

As noted above, the experiment was planned to measure k for rigid-foam materials over a range of temperature from +90°F to -290°F. The +90°F datum point was determined by taking measurements while the tester was suspended in air at room temperature. Air was circulated around it with an electric fan. The -290°F point was determined by submerging the test unit in LN_2. Values for k_{m_1} are reported in engineering units of Btu-in./ft^2-hr-°F.

For the irradiation portions of the experiment, the test units were mounted in the dewar and the dewar placed in irradiation position next to the face of the reactor closet. During the irradiation, LN_2 was maintained in the dewar at a level 3 in. above the top cap of the unit. After the unit had received the prescribed dose of radiation, the reactor was shut off and a k-value measurement made as a postirradiation operation. The planned doses were specified in terms of the gamma portion of the incident-radiation and amounted to 10^9 ergs/gm(C) for the low dose and 10^{10} ergs/gm(C) for the high dose.

IV. TEST MATERIALS

4.1 Basis for Selection

The selection of materials was based upon previously observed properties of the materials (and/or families of materials) in various applications and environments. Desired properties and applications, in order of importance for selection for testing in this experiment, are as follows:

1. Engineering properties suitable for use in rocket vehicles. Retention of these properties at cryotemperatures. Retention of these properties after irradiation. Previous successful use in rocket vehicles.

2. Engineering properties suitable for use in rocket vehicles. Retention of these properties at cryotemperatures. Possible (but not previously measured) retention of these properties after irradiation. Previous successful use in rocket vehicles.

3. Engineering properties suitable for use in rocket vehicles. Possible (but not previously measured) retention of these properties at cryotemperatures. Insignificant degradation of properties due to radiation. Previous successful use in rocket vehicles.

4. Engineering properties suitable for use in rocket vehicles, and previous successful use in rocket vehicles.

5. Engineering properties suitable for use in rocket vehicles.

Seven material categories were originally specified for testing: adhesives, structural laminates, seals, sealants, electrical insulations, thermal insulations, and potting compounds. As the program progressed, Teflon was added as a dielectric material.

It was tested under LN_2 temperature conditions only, ambient-air data having been obtained in the 1962 program (see Ref. 2).

As noted above, the procedure used for selection of the materials was based upon a series of five combinations of desirable properties and applications, with an order of importance to be used in the process of elimination. This series was used primarily as a reference in the selection procedure and not as an iron-clad rule, because other factors not listed became influential in some cases.

One additional, and important, consideration was whether or not the material had been tested in the first year's work under the radiation-vacuum section of the original contract. If a material had not been tested in the radiation-cryotemperature environment during the first year but had been tested in the radiation-vacuum environment and had demonstrated good retention of its properties, then it was considered to be a prime candidate for consideration under the cryogenic portion of the 1963 program.

4.2 Material Description

All materials scheduled for testing in the 1963 program were selected and ordered from sources of supply during the first quarter of operation. Most of these were received at NARF during the month of March. Rigid urethane-foam blocks of CPR-20 and CPR-1021 were procured in October after the foamed-in-place system for the thermal-conductivity test assembly failed to function satisfactorily. Teflon TFE-7 (Material Q) was added to the original list to be tested in LN_2 during the fourth quarter of operation.

Table 4.1 lists all the materials selected along with the code letter of each, the trade name, the manufacturer, the chemical type or class, and the test plan. Preparation of the specimens is described below and in Appendix A.

4.3 Specimen Preparation

As soon as the materials scheduled for testing started to arrive, specimen preparation began and continued throughout the contract period. Improvements and modifications were made in the tensile dumbbell configurations and design several times during the year in an effort to continually improve performance. Modifications and alterations to the ASTM test specifications were required in order to adapt specimens to the cryogenic test assembly.

The diversification of material types required different and distinct specimen configurations. The Scotchweld AF-40 and Aerobond 422J adhesives tested for tensile-shear strength under ASTM D-1002 required lap-shear type specimens. Viton-B O-rings were tested as received in the leak-test assembly. Efforts were made to foam-in-place the thermal insulations Stafoam AA-402 and CPR-1021 in the thermal-conductivity container, but results were unsatisfactory and these materials were replaced by the rigid foams CPR-20 and CPR-1021 machined to fit the container. Potting compounds Epon 828/Z and EC-2273B/A were cast in special wire holders of a NASA-NARF design. Sealants EC-1949 and EC-1663 were

Table 4.1

Outline of Materials and Tests

Material			Test Environment		Tests		
Category	Code Letter	Trade Name and Manufacturer	Temperature	Total Gamma Dose [ergs/gm(C)]	Test Method	Specimen Type	Data Reported
Adhesive	A	Scotchweld AF-40, Minn. Mining and Manufacturing	Amb. air, LN_2	0, 1(10), 5(10) 0, 1(10), 5(10)	ASTM-D-1002-53T	Lap-shear	Ult. ten. shear strength
	B	Aerobond 422J, Adhesives Engr. Co.	Amb. air, LN_2	0, 1(10), 5(10) 0, 1(10), 5(10)	ASTM-D-1002-53T	Lap-shear	Ult. ten. shear strength
Seal	C	Viton B, Precision Rubber Co.	LN_2	1(10)	NARF leakage	O-ring as static seal	Pressure drop
	D	Polymer-SP, E.I. DuPont	Amb. air, LN_2	0, 5(9), 1(10) 0, 5(9), 1(10)	ASTM D-638	Tensile-dumbbell	Stress-strain, Ult. ten. and elong.
Thermal Insulation	E	Stafoam AA-402			NARF-designed	Foam-in-place in cylinder	Thermal conductivity
	F	CPR 20-2, CPR International Corp.	Amb. air, LN_2	0 0, 5(9), 5(10)	NARF-designed	Rigid foam cut to fit cylinder	Thermal conductivity
	G	CPR 1021-2, CPR International Corp.	Amb. air, LN_2	0 0, 5(9), 5(10)	NARF-designed	Rigid foam cut to fit cylinder	Thermal conductivity

Table 4.1 (cont'd)

Material			Test Environment		Tests		
Category	Code Letter	Trade Name and Manufacturer	Temperature	Total Gamma Dose [ergs/gm(C)]	Test Method	Specimen Type	Data Reported
Electrical Insulation	H	GEON 8800, B.F. Goodrich	Amb. air, LN_2	0, 5{9}, 1{10} 0, 5{9}, 1{10}	ASTM-D-412-51T	Tensile-dumbbell	Stress-strain, Ult. ten. and elong.
	I	Duroid 5600, Rodgers Corp.	Amb. air, LN_2	0, 5{9}, 1{10} 0, 5{9}, 1{10}	ASTM-D-638-61T	Tensile-dumbbell	Stress-strain, Ult. ten. and elong.
Electrical Laminate	J	Lamicoid 6038E, Minn. Mining and Manufacturing	Amb. air, LN_2	0, 1{10}, 5{10} 0, 1{10}, 5{10}	ASTM-D-638-61T	Tensile-dumbbell	Stress-strain, Ult. ten. and elong.
Structural Laminate	K	CTL-91-LD, American Reinforced Plastics	Amb. air, LN_2	0, 1{10}, 5{10} 0, 1{10}, 5{10}	ASTM-D-638-61T	Tensile-dumbbell	Stress-strain, Ult. ten. and elong.
	L	DC-2104, Dow Corning Corp.	Amb. air, LN_2	0, 1{10}, 5{10} 0, 1{10}, 5{10}	ASTM-D-638-61T	Tensile dumbbell	Stress-strain, Ult. ten. and elong.

Table 4.1 (cont'd)

Material			Test Environment		Tests		
Category	Code Letter	Trade Name and Manufacturer	Temperature	Total Gamma Dose [ergs/gm(C)]	Test Method	Specimen Type	Data Reported
Potting Compound	M	Epon 828/Z, Shell Chemical Corp.	Amb. air, LN_2	0, 5(9), 1(10) 0, 5(9), 1(10)	NASA-NARF designed holder	Potted wires	Pull-out load of potted wires
	N	EC-2273B/A, Minn. Mining and Manufacturing	Amb. air, LN_2	0, 5(9), 1(10) 0, 5(9), 1(10)	NASA-NARF	Potted wires	Pull-out load of potted wires
Sealant	O	EC-1949, Minn. Mining and Manufacturing	Amb. air, LN_2	0, 5(9), 1(10) 0, 5(9)	ASTM-D-1876-61T	T-peel	T-peel strength
	P	EC-1663, Minn. Mining and Manufacturing	Amb. air, LN_2	0, 1(10), 5(10) 0, 1(10), 5(10)	D-1876-61T	T-peel	T-peel strength
Dielectric	Q	Teflon TFE-7, E. I. DuPont	LN_2	0, 1(8), 1(9)	ASTM-D-638-61T	Tensile dumbbell	Stress-strain, Ult. ten. and elong.

tested as T-peel specimens under ASTM-D-1876 (modified). The remaining materials tested were prepared in the form of tensile dumbbells according to ASTM D-412 or D-828, with modifications as shown.

Special arrangements for testing the specimens under cryogenic conditions required modifications in the construction of the specimen ends in order to pull the test specimens by remotely controlled equipment. In addition, the dumbbell-type and lap-shear type tensile specimens of nonmetallic materials required aluminum doublers on the ends for added strength in the slotted-hole section.

The doublers were bonded according to Shell technical instructions. The acid-dichromate-etched 2024-T3 Alcad aluminum alloy doublers were bonded with Shell Epon 934. After drying overnight under just enough pressure (C-clamp) to obtain good bonding contact, they were oven-cured for 1 hr at 200°F. The surfaces were cleaned with methyl ethyl ketone (MEK) before bonding. The bonds held very well in LN_2.

For the ambient-air and low-dose LN_2 irradiations, only enough specimens were fabricated to reveal any testing problems that might arise as a result of specimen shapes or sizes, doubler application, or slot drillings. These problems could then be corrected in specimens used in succeeding tests. This approach proved to be advantageous, since modifications to the original specimen designs were necessary.

The Dow Corning 2104 silicone laminate delaminated in the doubler section when submerged in LN_2. For subsequent runs, the doublers, in addition to being bonded, were riveted at the four corners of the long doublers and at the outside corners of the short doublers. All silicone laminates, when riveted, held in the doubler section.

The Geon 8800 specimens broke in the doubler sections and, in some cases, the doublers came off. In an attempt to prevent this breakage, the aluminum doublers were replaced with Geon doublers. The Geon doublers helped, but some specimens still broke in this area when tested in LN_2. To further reduce undesirable stress in the ends of Geon 8800 specimens, the center cross section of the remaining specimens was changed from a wide to a narrow gage. Results of these modifications will be reviewed in the data sections.

The Polymer-SP specimens did not break in the middle of the gage section; instead, they broke near the doublers and were often removed from the experimental assembly in several pieces. The center section was then reduced from the initial wide gage to the narrow gage, but the results were essentially the same as before.

The John L. Dore Company of Houston supplied Teflon TFE-7 specimens with etched ends that proved to be very satisfactory when properly bonded under pressure to aluminum doublers.

Drawings of the lap-shear specimens, giving dimensions and arrangements of doublers, are shown in Figures 4.1 and 4.2. In the initial dumbbell tensile-specimen design, the nonlaminate plastics were prepared with a 1/2-in. gage width. Some modifications were made as noted above. The laminates were designed

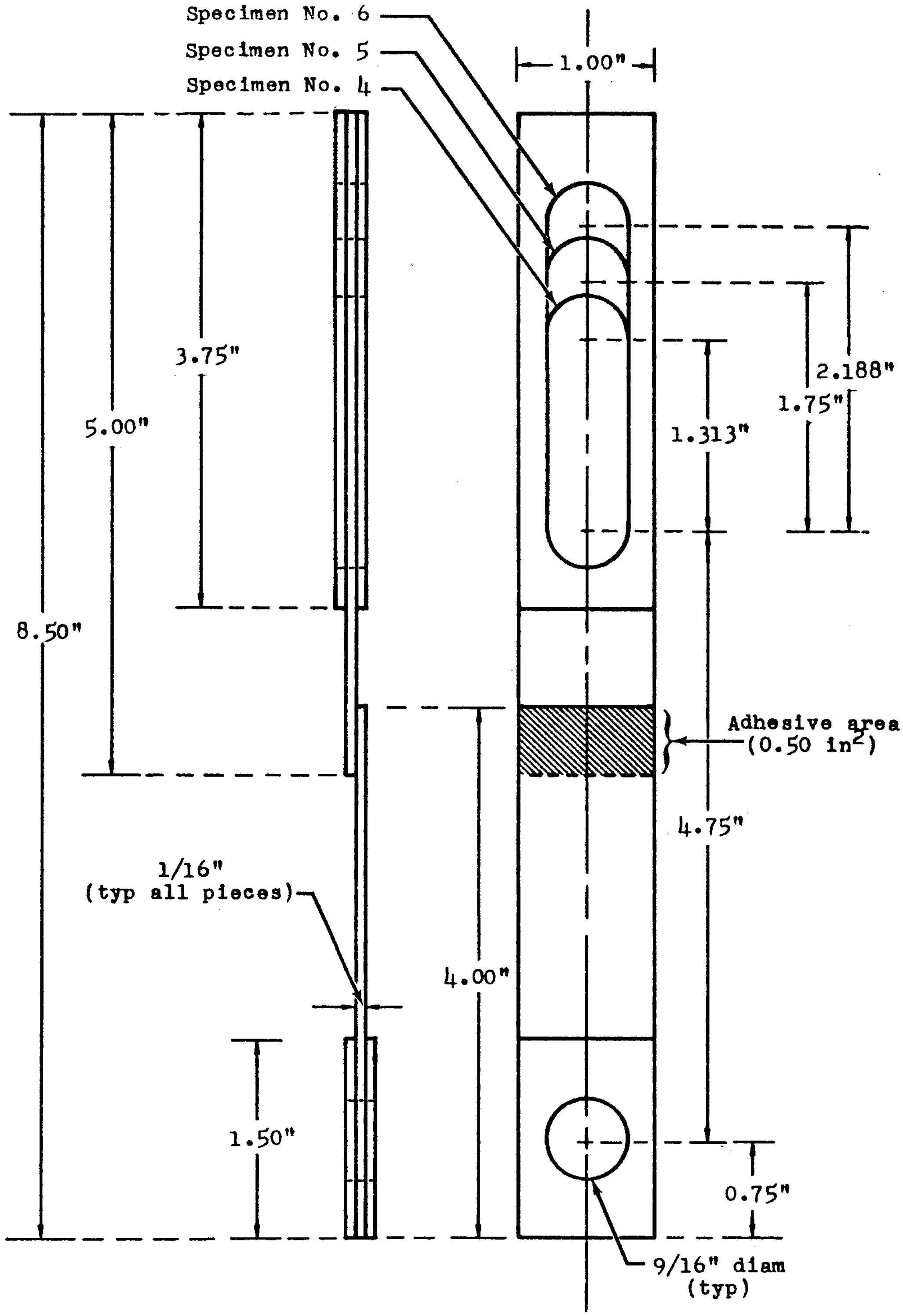


Figure 4.1 Sketch of Lap-Shear Specimen: Material A

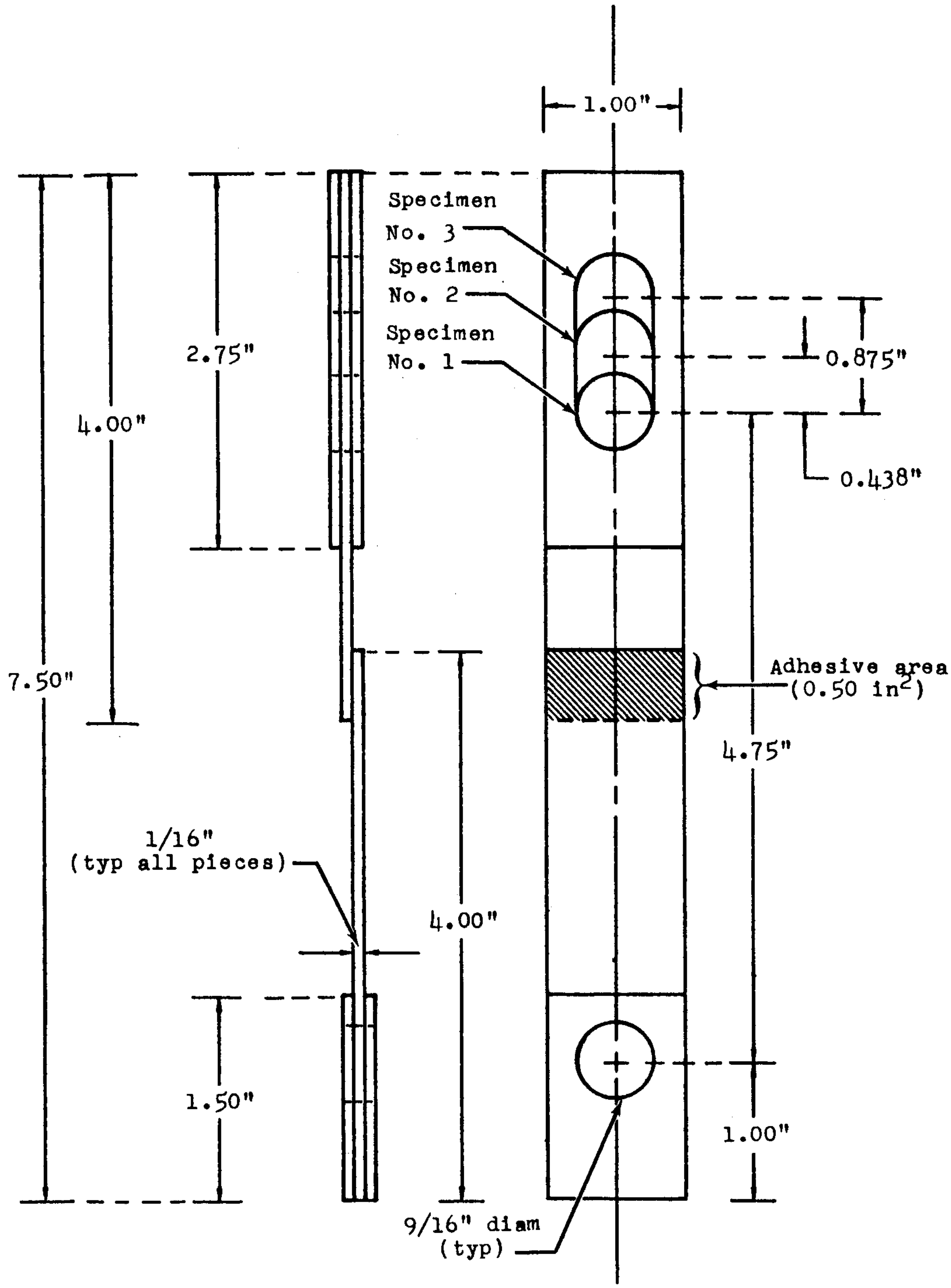


Figure 4.2 Sketch of Lap-Shear Specimen: Material B

with a 1/4-in. gage width. All tensile dumbbell materials had a nominal sheet thickness of 1/8-in. Figures 4.3 and 4.4 show details of the two dumbbell-type designs. Figure 4.5 is a drawing of the potted-wire tester, and Figure 4.6 is a drawing of the T-peel specimens.

In a few cases, the slotted holes were moved and arranged differently and the doubler lengths varied slightly for convenience or as a safety measure, but the specimens all had the essential features illustrated in the figures.

Table 4.2 lists all the materials prepared as specimens, along with the number of specimens tested under various conditions in the ambient and LN_2 tests. A total of 352 specimens of the 13 materials were tested. The thermal-conductivity materials and the leak-test specimens are not included in this table.

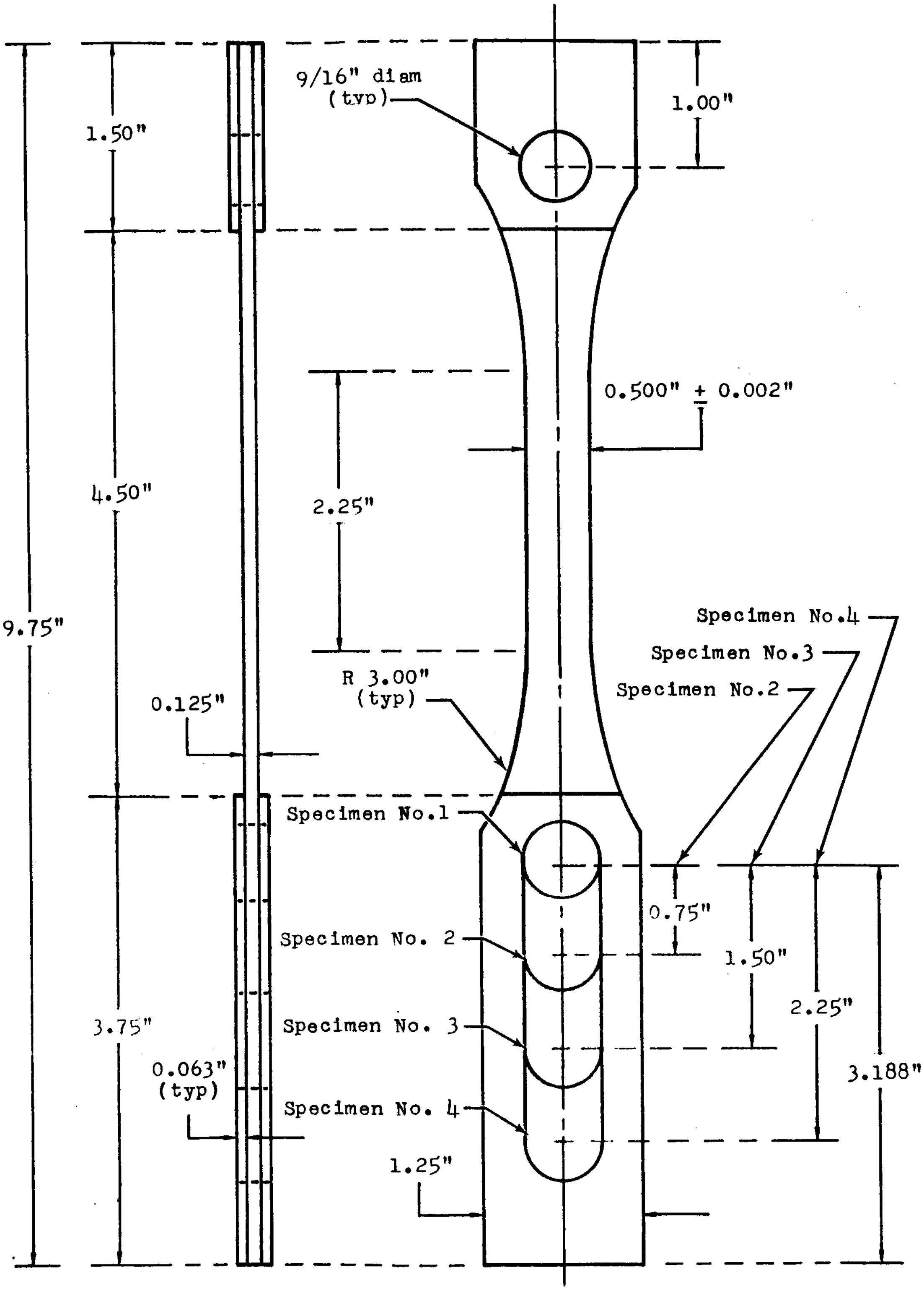


Figure 4.3 Sketch of Dumbbell-Type Specimen: Materials I, Q, and Original D and H

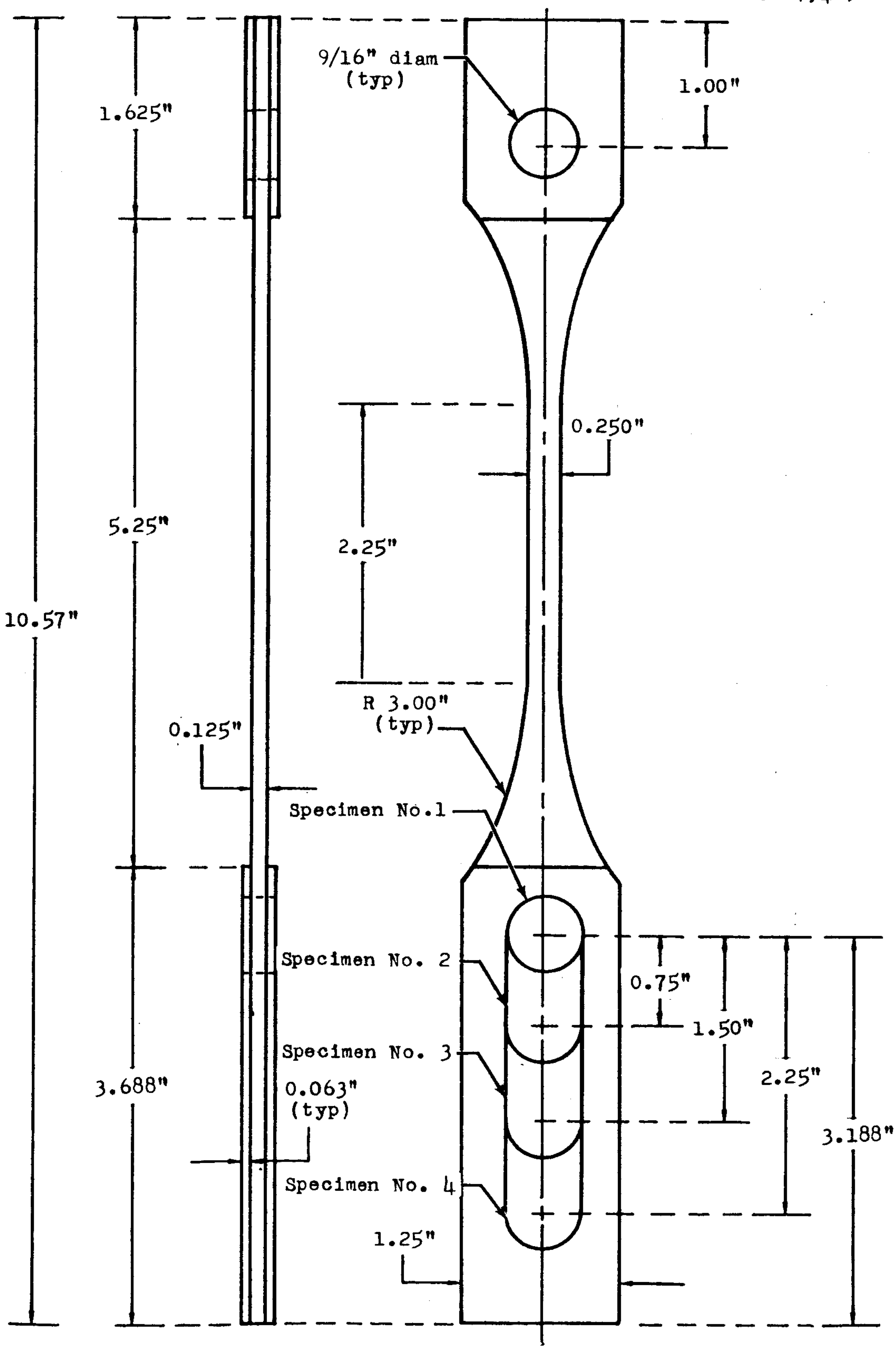


Figure 4.4 Sketch of Dumbbell-Type Specimen: Materials J, K, and L and Modified D and H

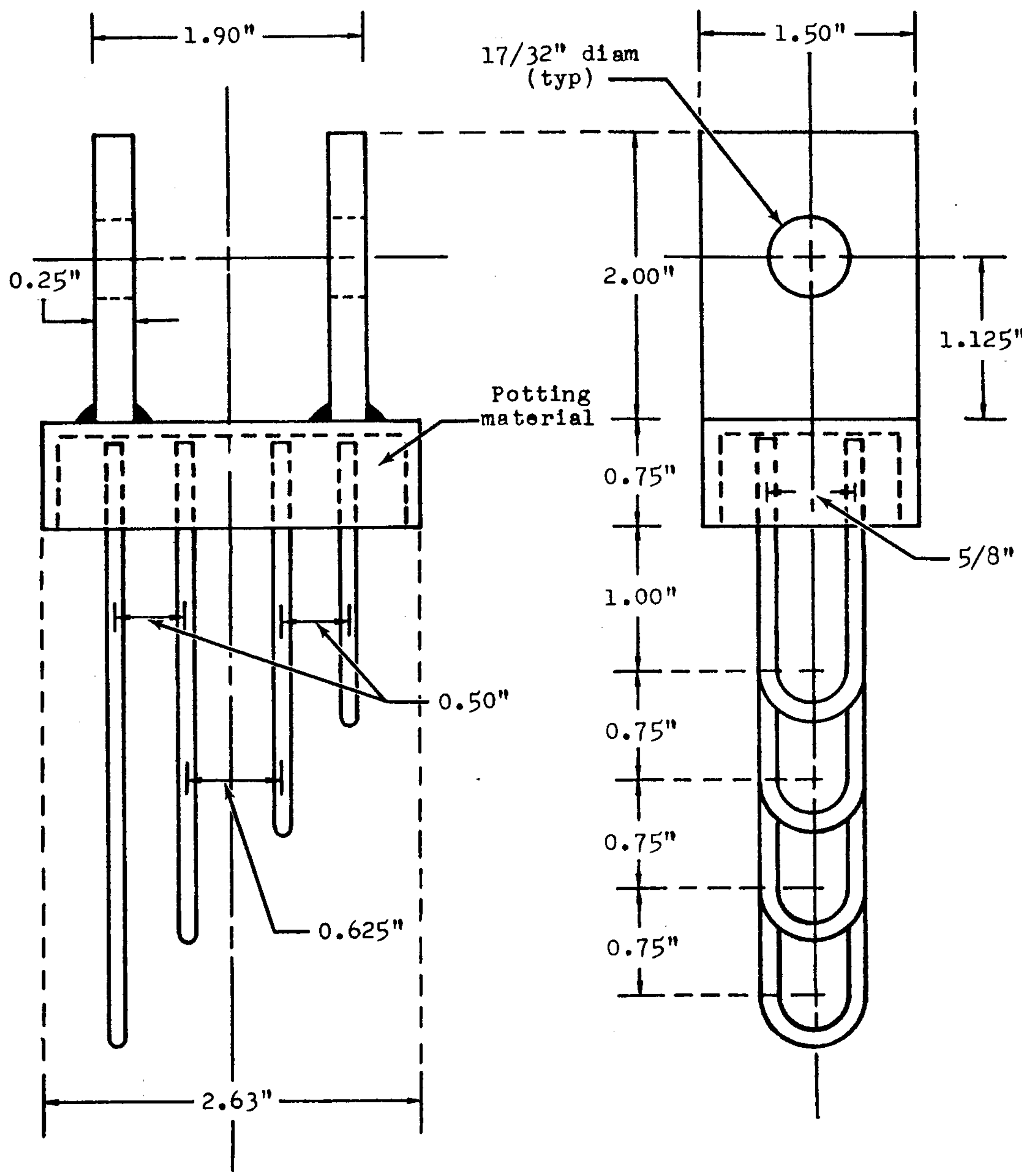


Figure 4.5 Sketch of Potted-Wire Tester: Materials M and N

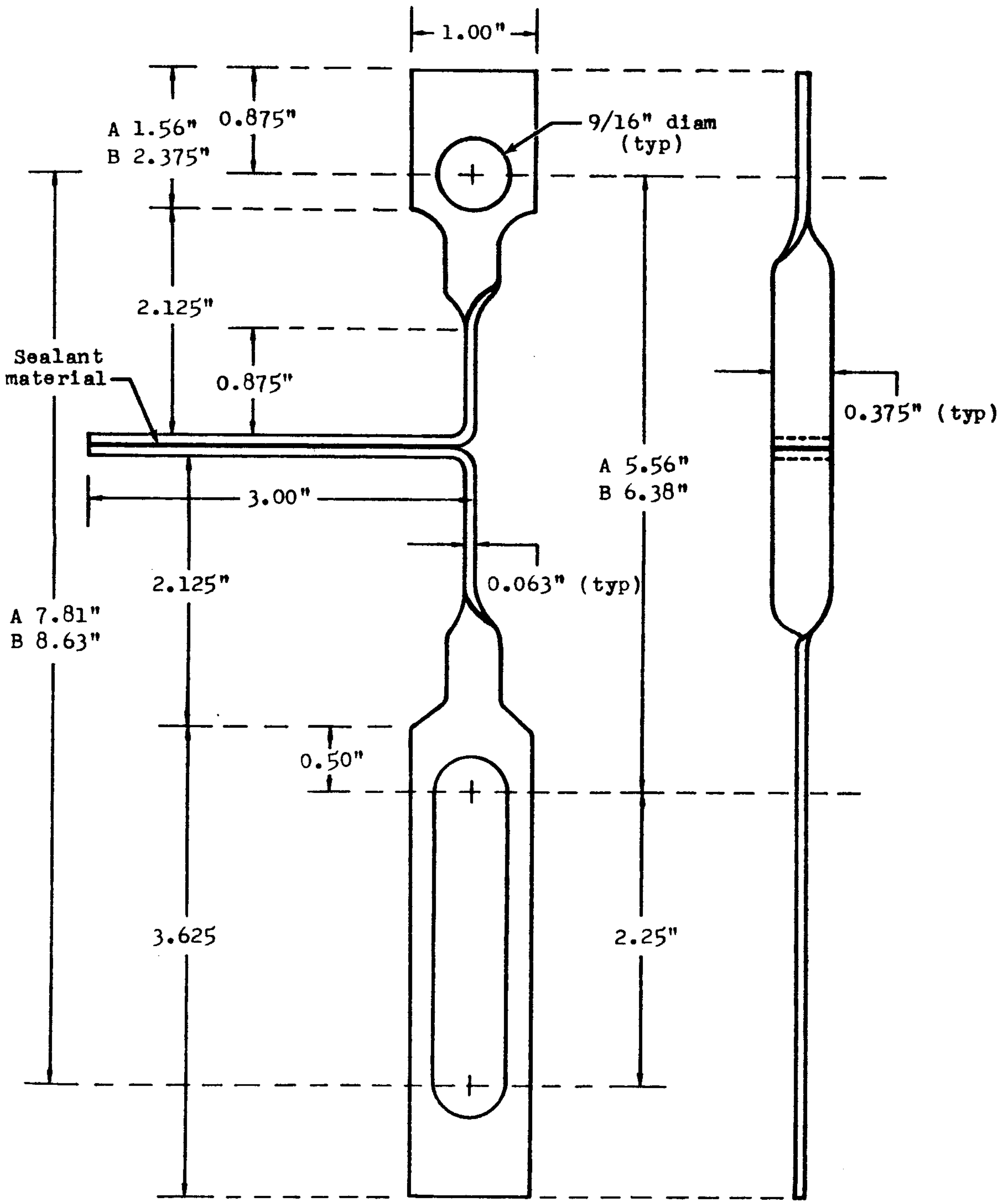


Figure 4.6 Sketch of T-Peel Tester (Types A & B): Materials O and P

Table 4.2

Total Number of Specimens Tested

Code Letter	Material	Ambient Runs Con-trols	Ambient Runs Low Dose	Ambient Runs High Dose	LN_2 Runs Con-trols	LN_2 Runs Low Dose	LN_2 Runs High Dose	Total No.
A	Scotchweld AF-40	39	3	3	3	3	3	54
B	Aerobond 422J	8	3	3	3	3	3	23
D	Polymer-SP	7	6	6	6[a]	6	3	34
H	Geon 8800	7	6	6	7	6	3	35
I	Duroid 5600	4	6	6	6	6	3	31
J	Lamicoid 6038E	8	4	3	3	3	3	24
K	CTL-91LD	8	6	6	3	3	3	29
L	DC-2104	8	6	6	6	3	3	32
M	Epon 828/Z	4	4	4	4	4	4	24
N	EC-2273B/A	4	4	4	4	4	4	24
O	EC-1949	4	3	3	2	3	0	15
P	EC-1663	4	3	3	2	3	3	18
Q	Teflon, TFE-7	0	0	0	3[b]	3	3	9
Totals		105	54	53	52	50	38	352

[a] One extra specimen pulled with bucket dewar on Instron
[b] Two extra specimens (one pulled after dipping in LN_2, one pulled with bucket dewar on Instron)

V. RADIATION MEASUREMENTS

5.1 Neutron Monitoring Procedure

The neutron flux was monitored during the irradiations at several material locations. Measurements were made with sulfur for fast-neutron flux and phosphorous for thermal-neutron flux. Standard foil techniques were used in specifying the neutron field (Ref. 6).

Detectors were mounted on 3-1/2- by 3-in. aluminum plates which, in turn, were mounted on or near the components. All foils were counted and the data reduced by an IBM 7090 digital computer program.

5.2 Gamma Monitoring Procedure

The gamma dose inside the LN_2 dewars was obtained by exposing nitrous oxide (N_2O) dosimeters (Ref. 7) outside the dewars at both the front and back faces and interpolating between the measurements.

The N_2O dosimeters used at NARF consist of a 24-cc quartz shell filled with a measured quantity of N_2O gas, then flame-sealed. Upon exposure to gamma radiation, the following reaction is produced in the gas:

$$6\ N_2O \longrightarrow 5\ N_2 + O_2 + 2\ NO_2.$$

Readout is accomplished by measuring the moles of $N_2 + O_2$ produced per mole of original N_2O and then relating this ratio to the gamma dose by means of a calibration curve.

Energy dependence of the N_2O system is air-equivalent (within 10%) between 150 kev and 5 Mev. The dosimeters are usable in the dose and temperature ranges of from 10^8 to 10^{12} ergs/gm(C) and -90° to $+120^\circ C$, respectively, with a reproducibility of 7 to 9% in the GTR field.

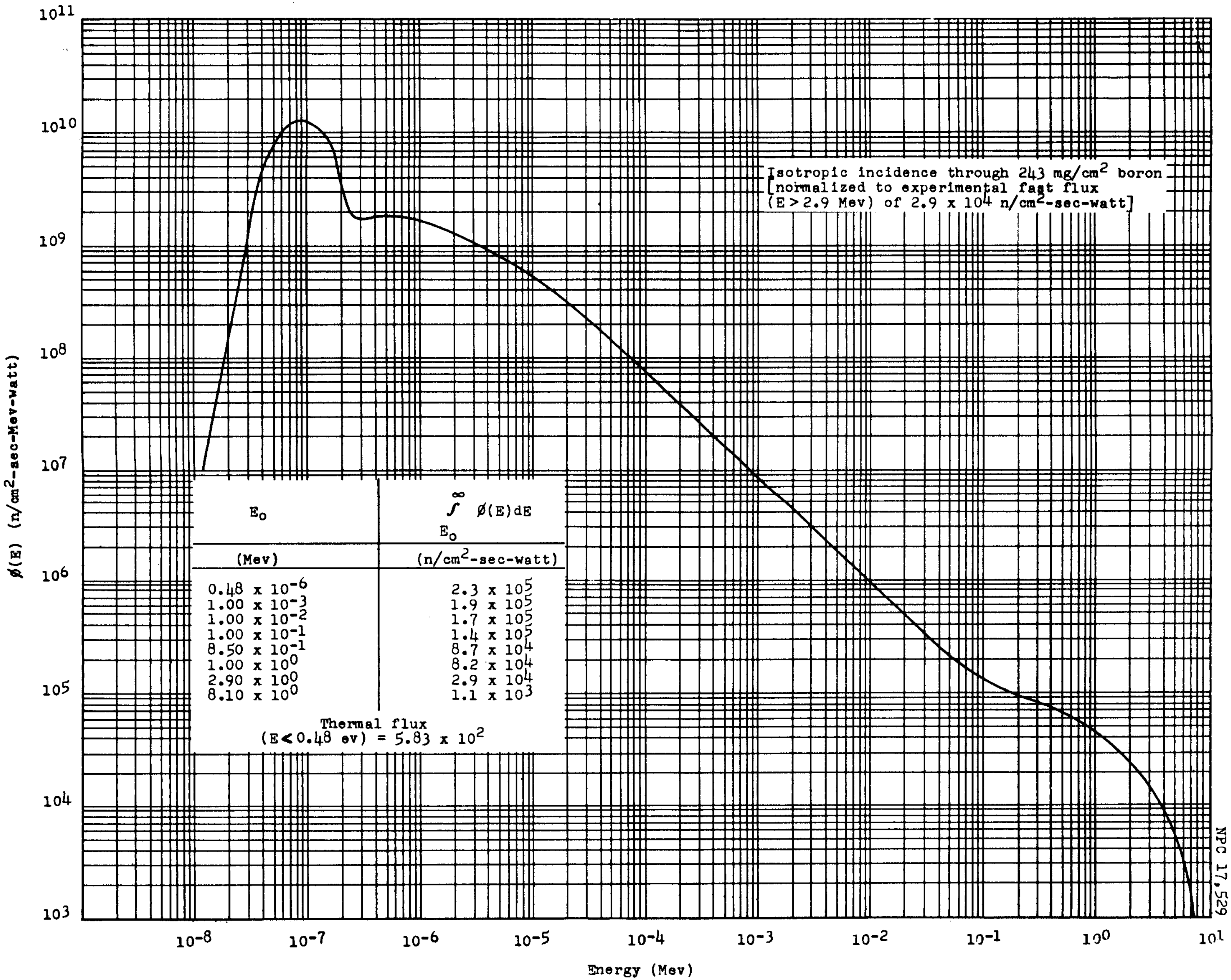
5.3 Analytical GTR Neutron Spectrum

The neutron spectrum (Ref. 5) of the GTR in a water moderator has been measured to be Maxwellian at thermal energies ($E < 0.48$ ev), approximately proportional to E^{-1} from about 0.5 ev to 0.1 Mev; and essentially a fission spectrum for higher energies. In Figure 5.1, this spectral shape has been mathematically altered to account for the attenuation of the thermal flux by the boral surrounding the reactor in the dry-pool configuration. The resulting spectrum has been shown to represent the actual spectrum fairly accurately.

Flux measurements have been made in the thermal-, epithermal-, and fast-neutron energy ranges by use of a variety of thermal, resonance, and threshold detectors. Fast-neutron flux measurements ($E > 2.9$ Mev) made in the dry side with the boral in place agree well with those made in the wet (pool) side. The measured thermal flux is in general agreement with that obtained by integration of the analytical curve shown in Figure 5.1.

5.4 Mapping Irradiation

The neutron fluxes and gamma dose rates in air along the core centerline perpendicular to the closet face and $\pm$ 10 in. off centerline have been well established for the east, west, and north irradiation positions of the Ground Test Reactor (GTR) at NARF (Ref. 8). These values are plotted in Figures 5.2



E_o (Mev)	$\int_{E_o}^{\infty} \phi(E)\,dE$ (n/cm^2-sec-watt)
0.48×10^{-6}	2.3×10^5
1.00×10^{-3}	1.9×10^5
1.00×10^{-2}	1.7×10^5
1.00×10^{-1}	1.4×10^5
8.50×10^{-1}	8.7×10^4
1.00×10^0	8.2×10^4
2.90×10^0	2.9×10^4
8.10×10^0	1.1×10^3

Thermal flux
(E < 0.48 ev) = 5.83×10^2

Figure 5.1 Analytical GTR Neutron Spectrum through 5.13. It should be noted that these data are established for a 4-in. thickness of water between the core and the north irradiation position and for a 4.25-in. thickness of water between the core and the east and west positions.

These data are successfully used in predicting doses for specimens irradiated in air at the three positions, but variations in established dose rates occur when metallic or organic structure is placed between the reactor core and the specimens being irradiated. Calculations can be made for these variations if the interposed material is uniform in shape, size, and density, but for other arrangements, a pre-test mapping irradiation is desirable.

It was decided this year that a mapping run for the NASA cryogenic experimental assemblies would be beneficial in predicting dose rates for specimens located below each of the ten pull rods. The plan involved operation of the reactor for two 1-hr runs at a power level of 1 Mw. During the first run, the east and north experimental assemblies were mapped. During the second, only the north assembly was mapped.

Dosimetry packets were mounted to the lower box frames of the assemblies. As can be seen in Figure 5.14, complete dosimetry packets were located at the exact sample positions for pull rods 1, 3, 5, 6, 8, and 10. Each packet contained one bare and one cadmium-covered silver-manganese foil to measure the thermal-neutron flux ($E < 0.48$ ev), one indium foil to measure the neutron flux for $E > 0.85$ Mev, one sulfur pellet to measure the

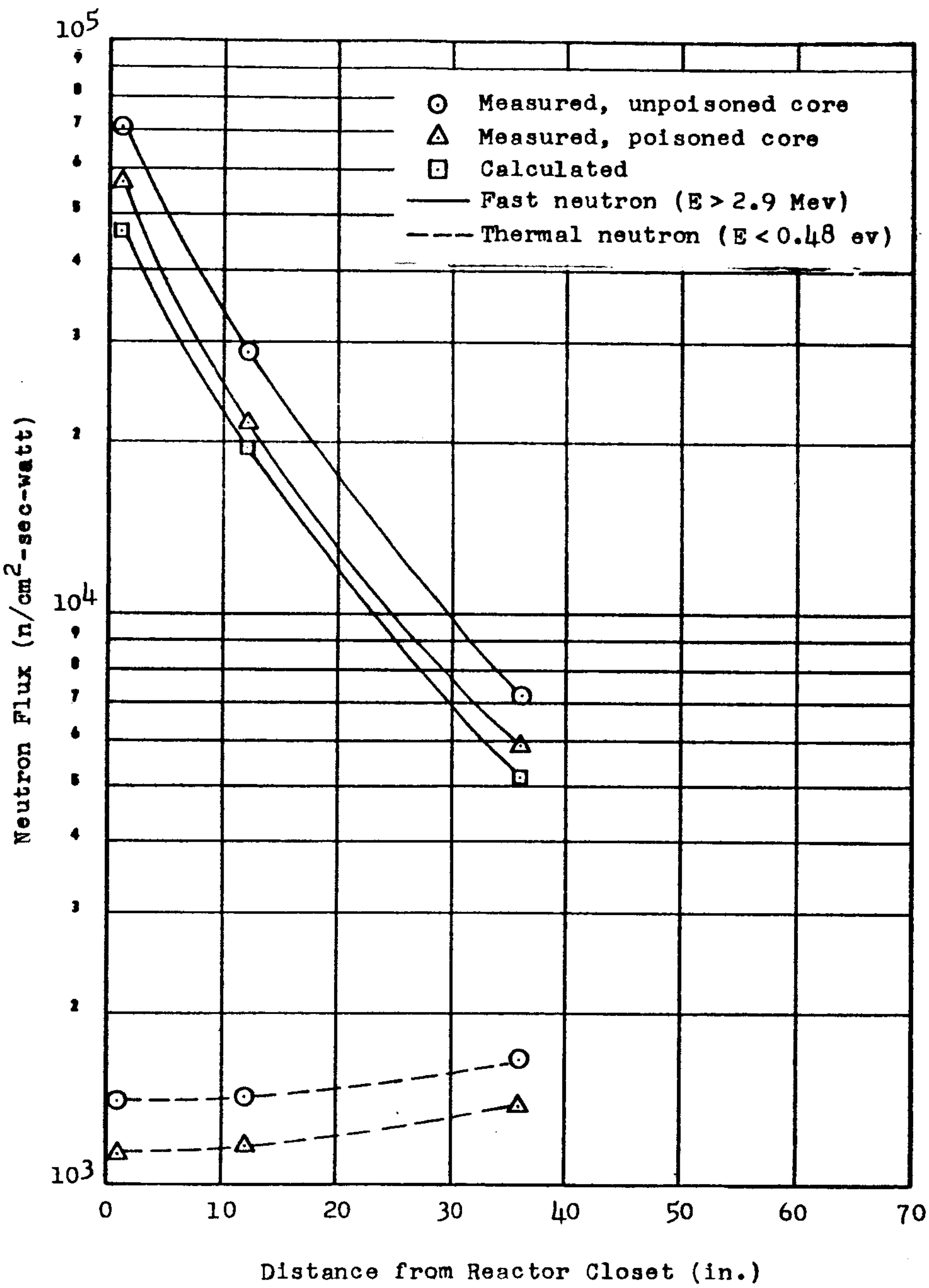


Figure 5.2 Average Neutron Flux along Rack Centerline: North Face

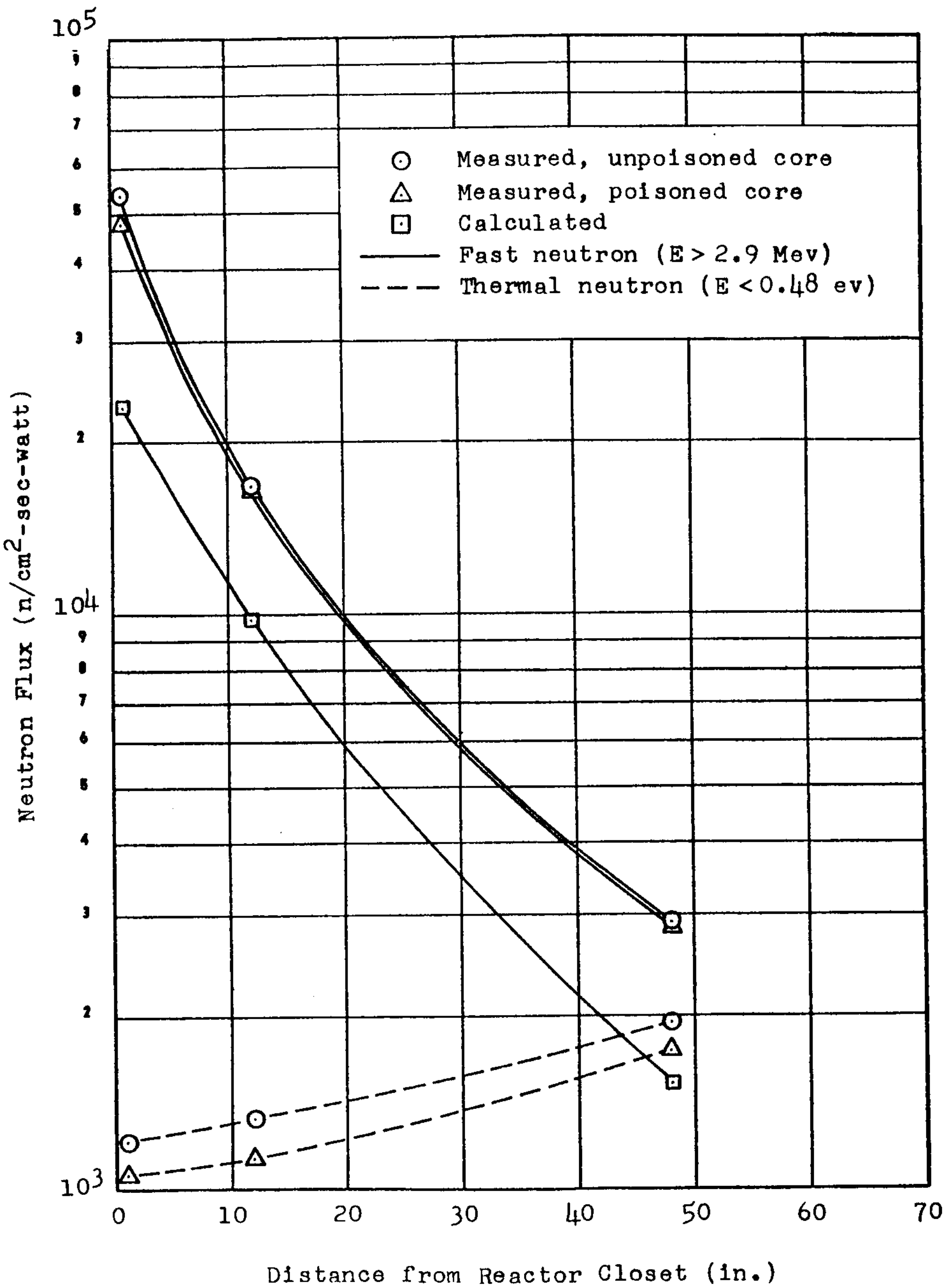


Figure 5.3 Average Neutron Flux along Rack Centerline: East Face

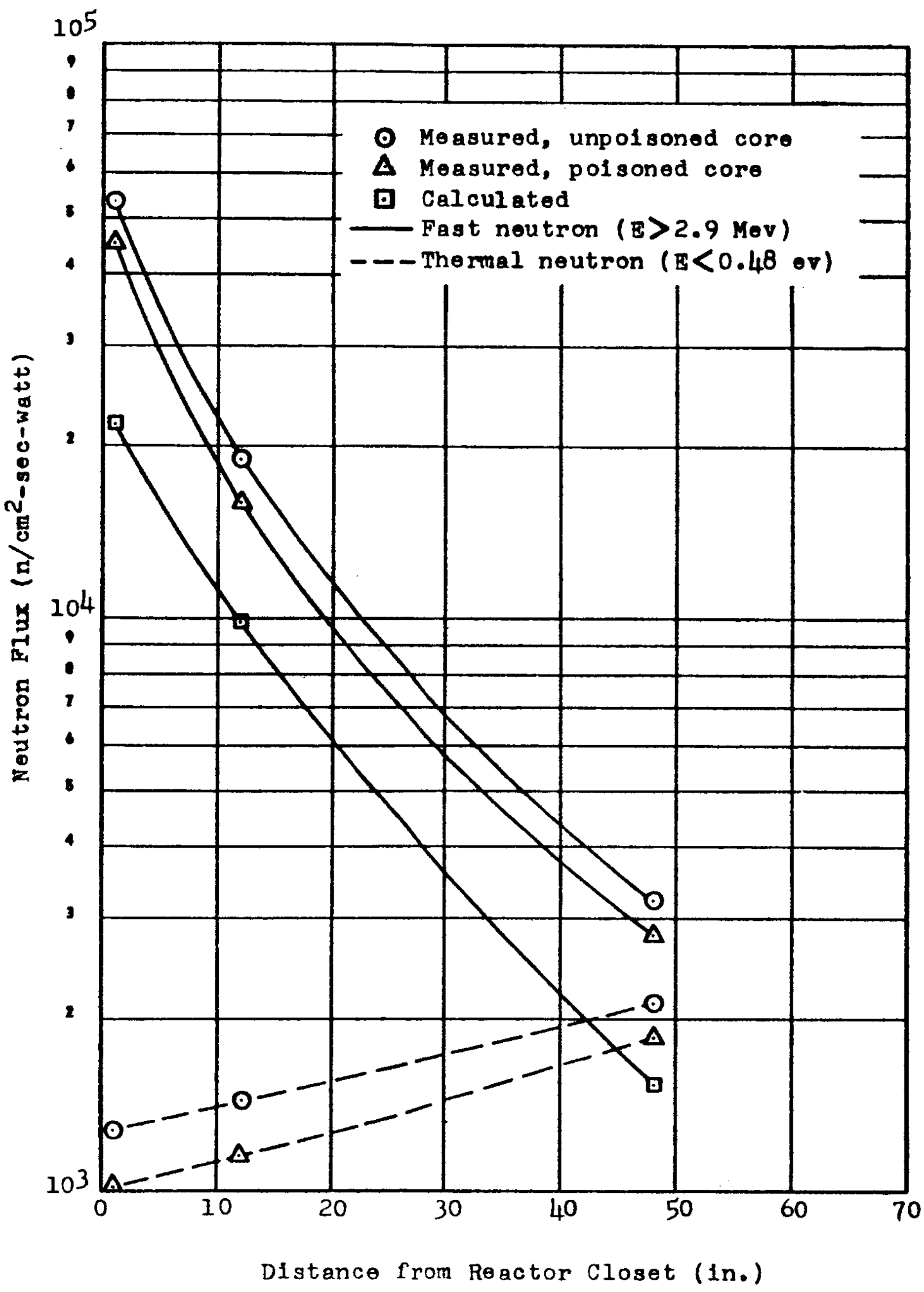


Figure 5.4 Average Neutron Flux along Rack Centerline: West Face

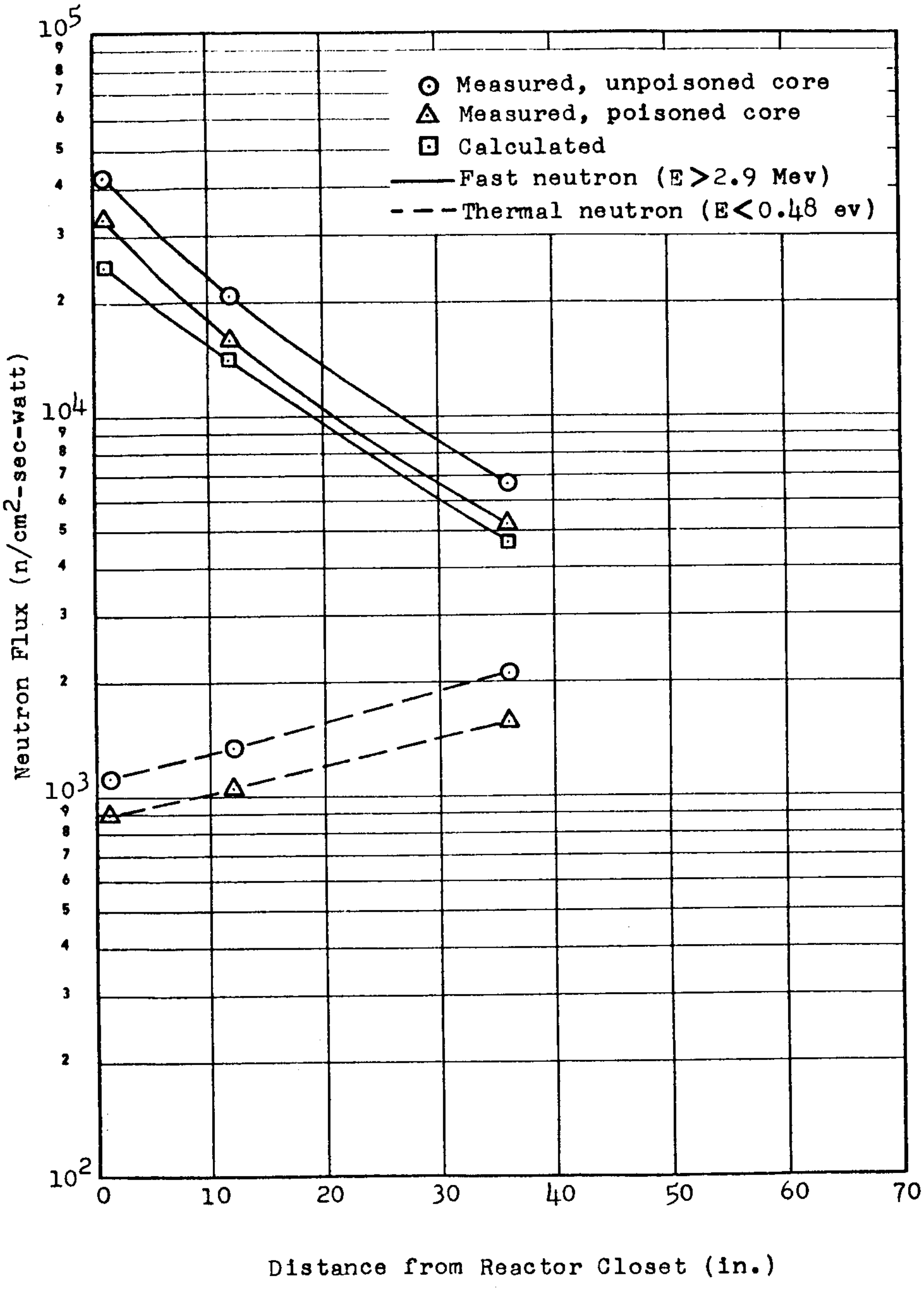


Figure 5.5 Average Neutron Flux 10 Inches off Rack Centerline: North Face

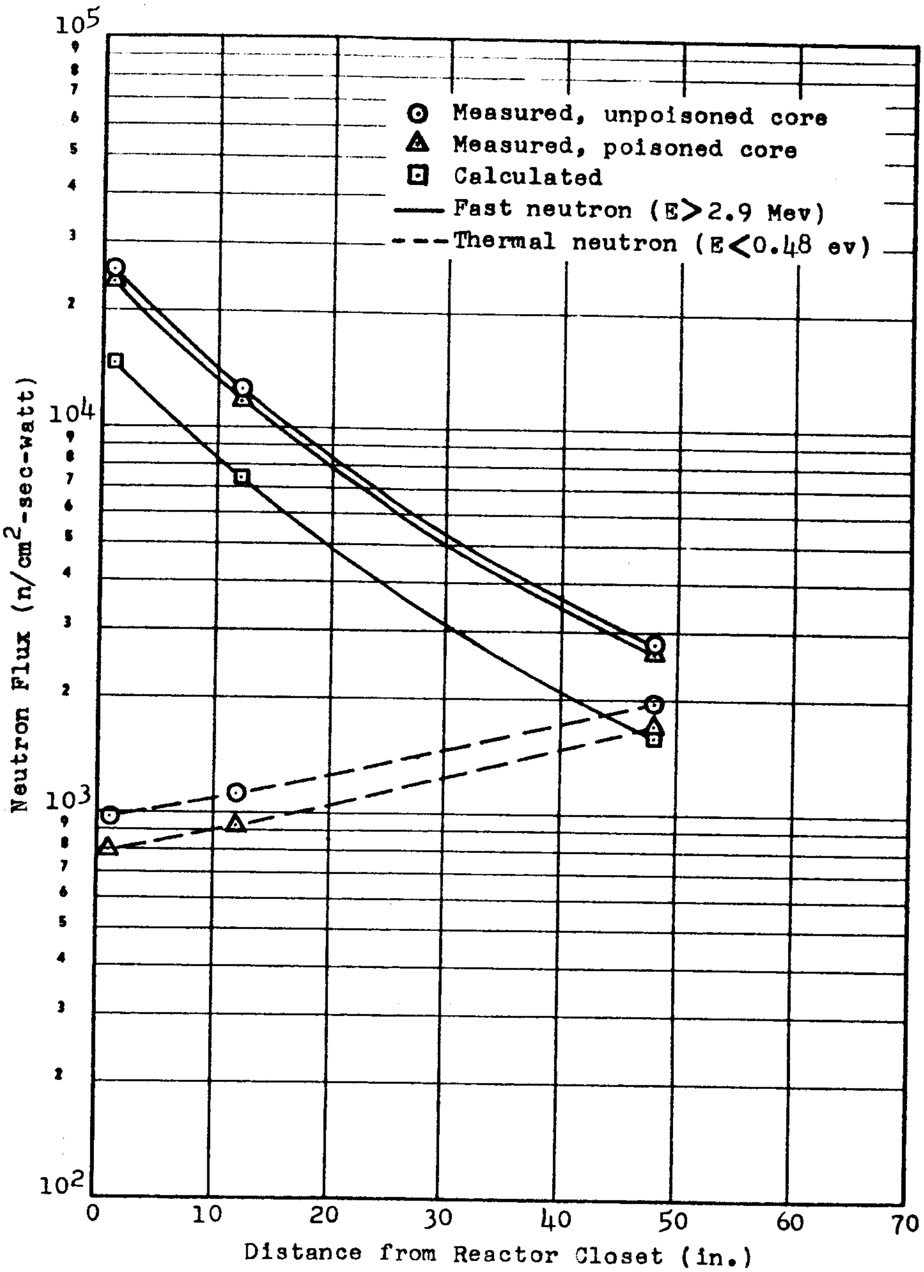


Figure 5.6 Average Neutron Flux 10 Inches off Rack Centerline: East Face

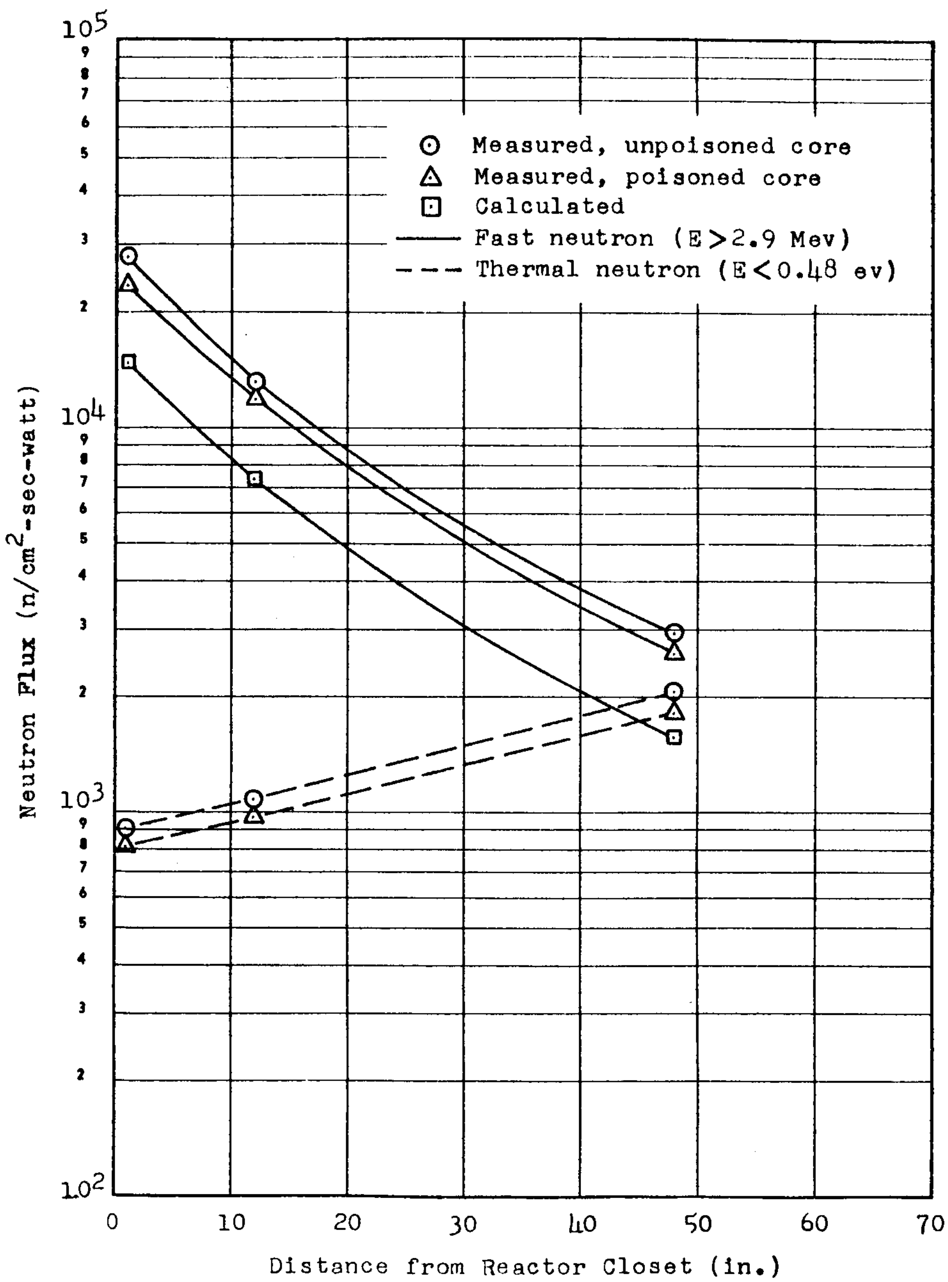


Figure 5.7 Average Neutron Flux 10 Inches off Rack Centerline: West Face

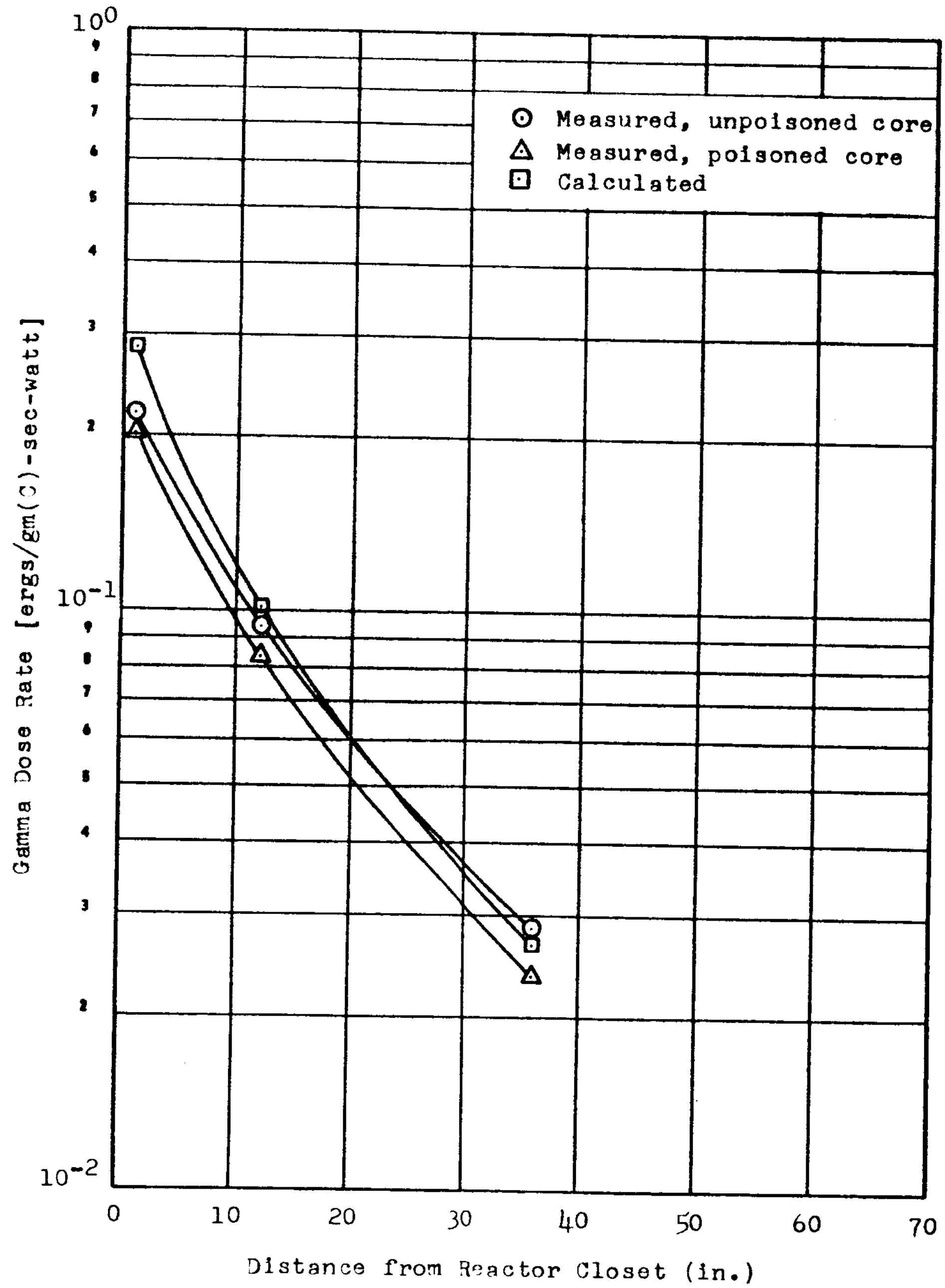


Figure 5.8 Average Gamma Dose Rate along Rack Centerline: North Face

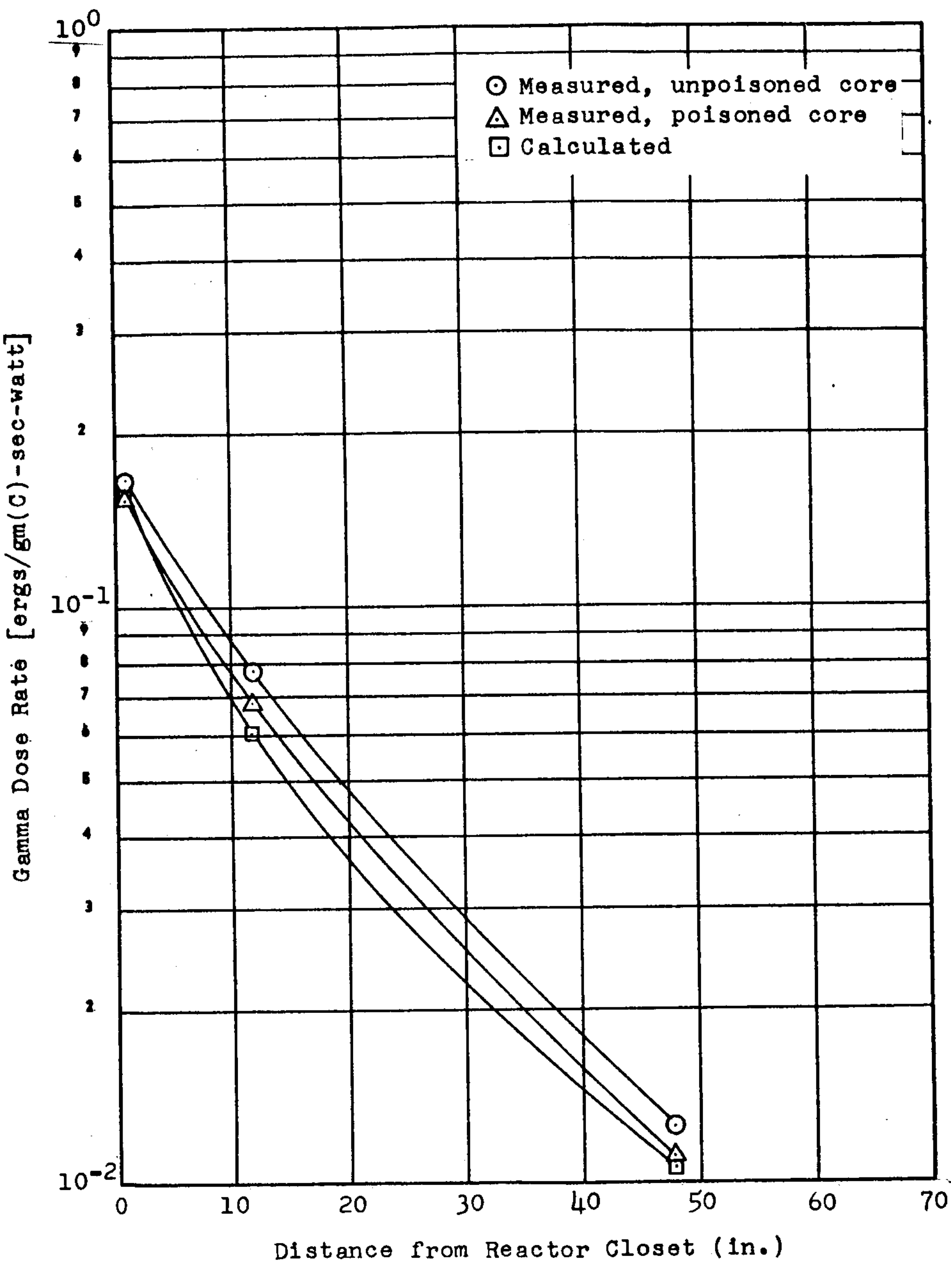


Figure 5.9 Average Gamma Dose Rate along Rack Centerline: East Face

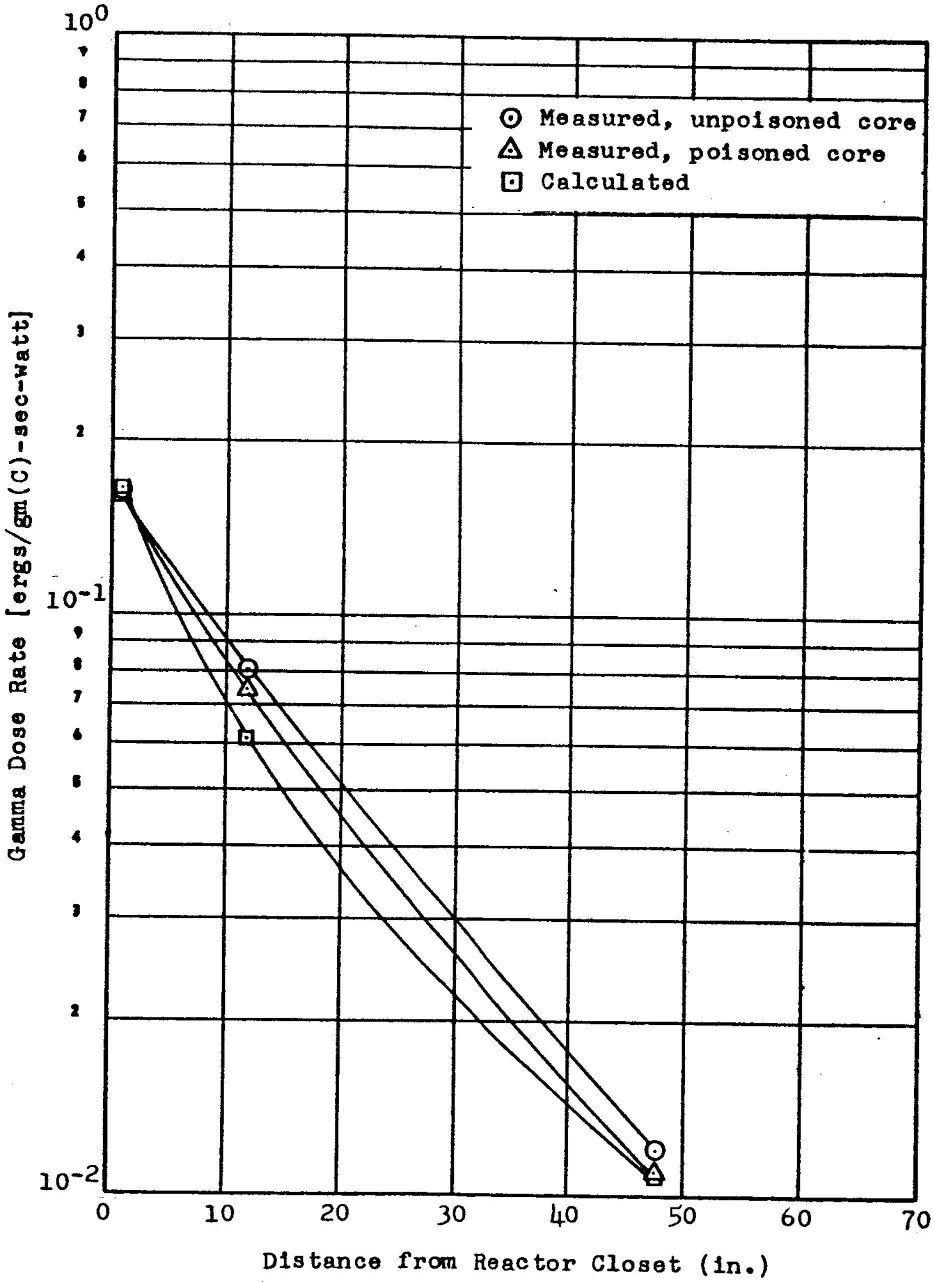


Figure 5.10 Average Gamma Dose Rate along Rack Centerline: West Face

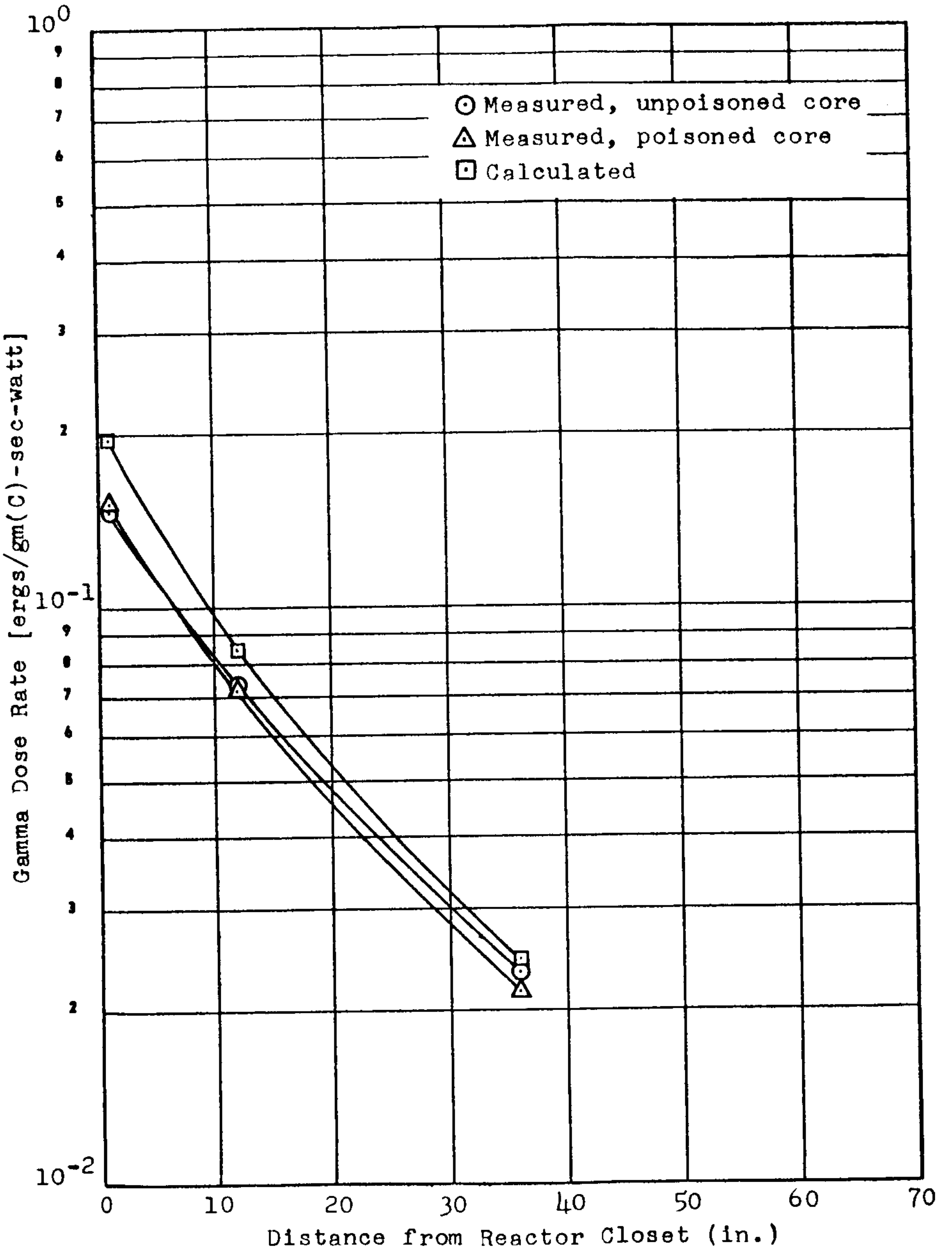


Figure 5.11 Average Gamma Dose Rate 10 Inches Off Rack Centerline: North Face

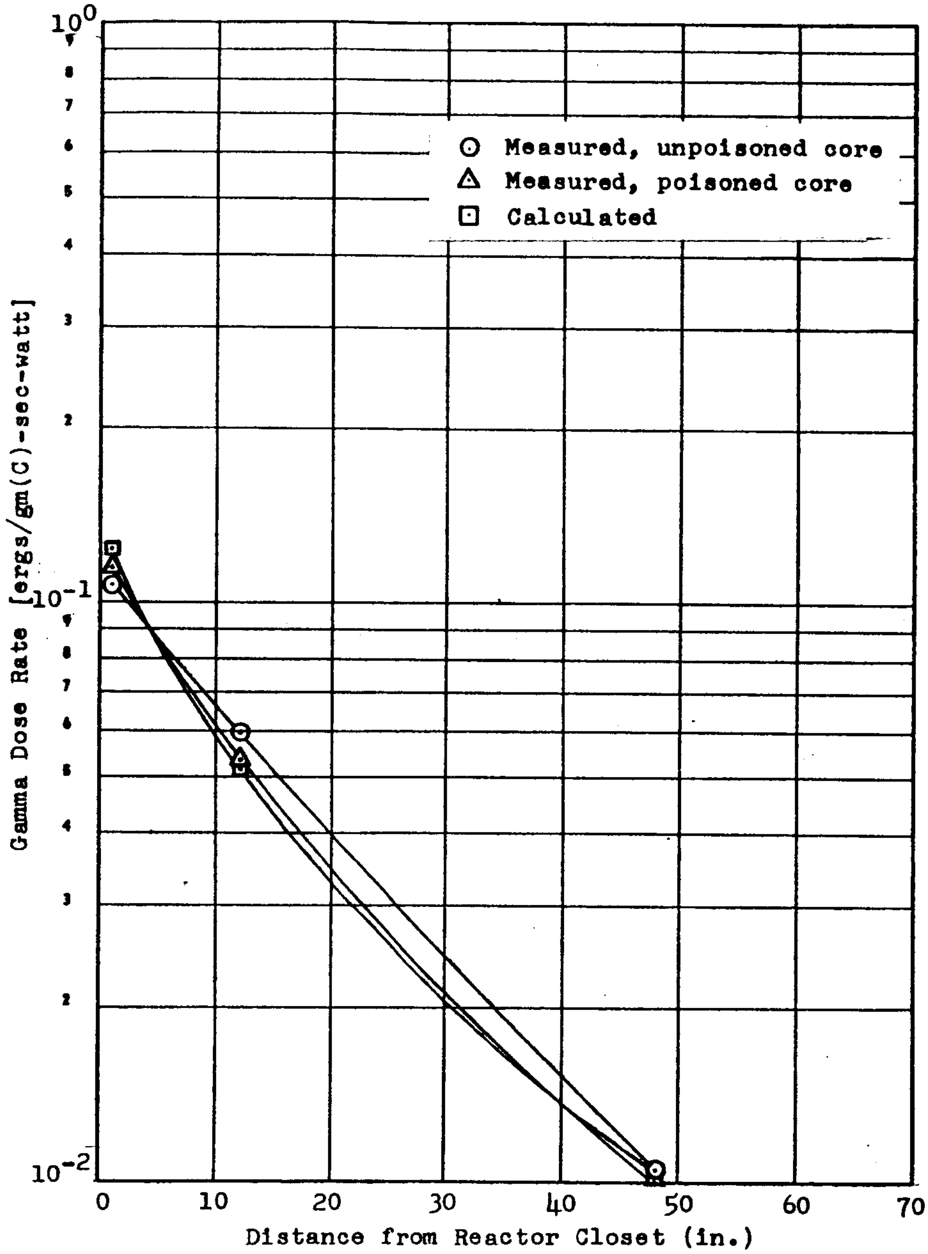


Figure 5.12 Average Gamma Dose Rate 10 Inches Off Rack Centerline: East Face

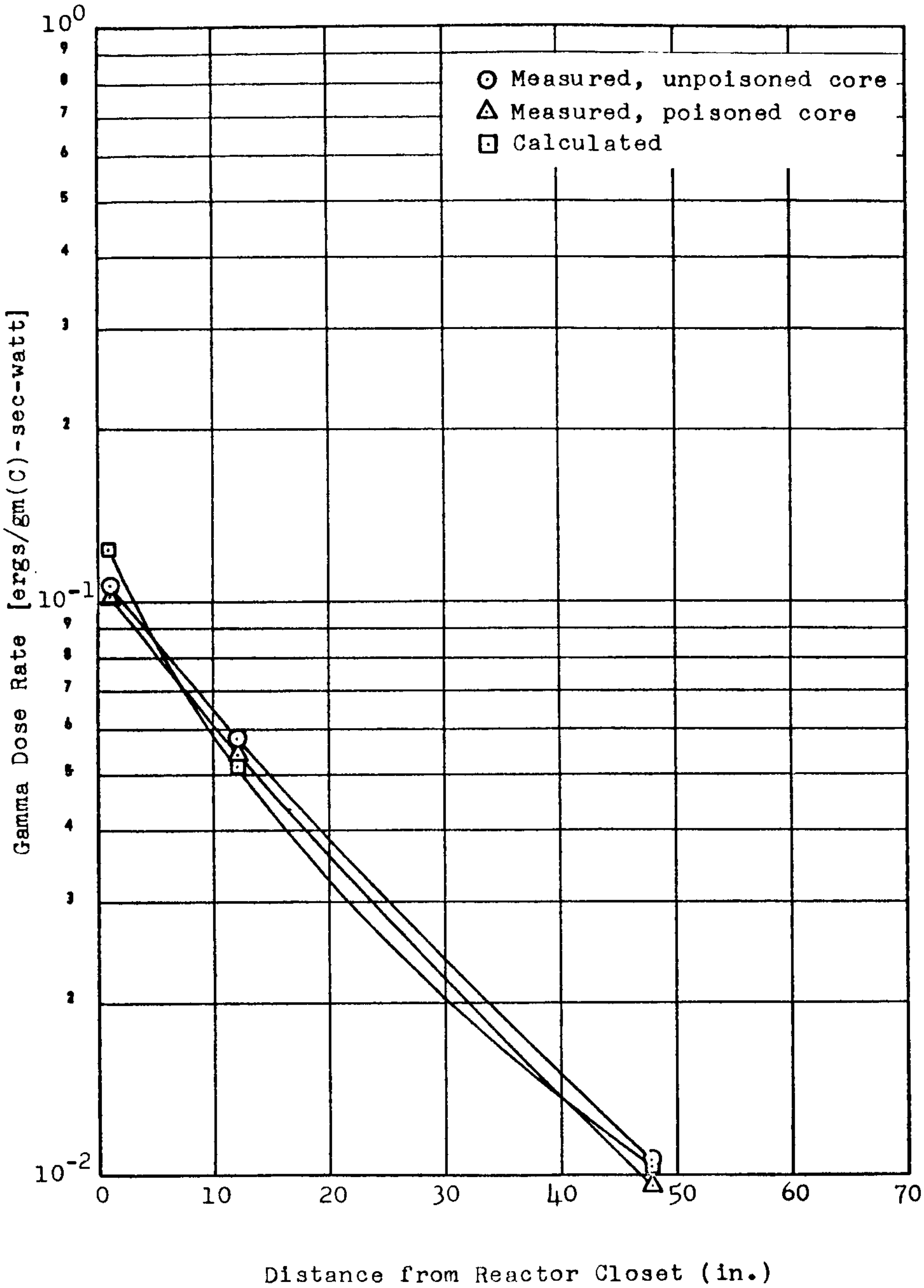


Figure 5.13 Average Gamma Dose Rate 10 Inches Off Rack Centerline: West Face

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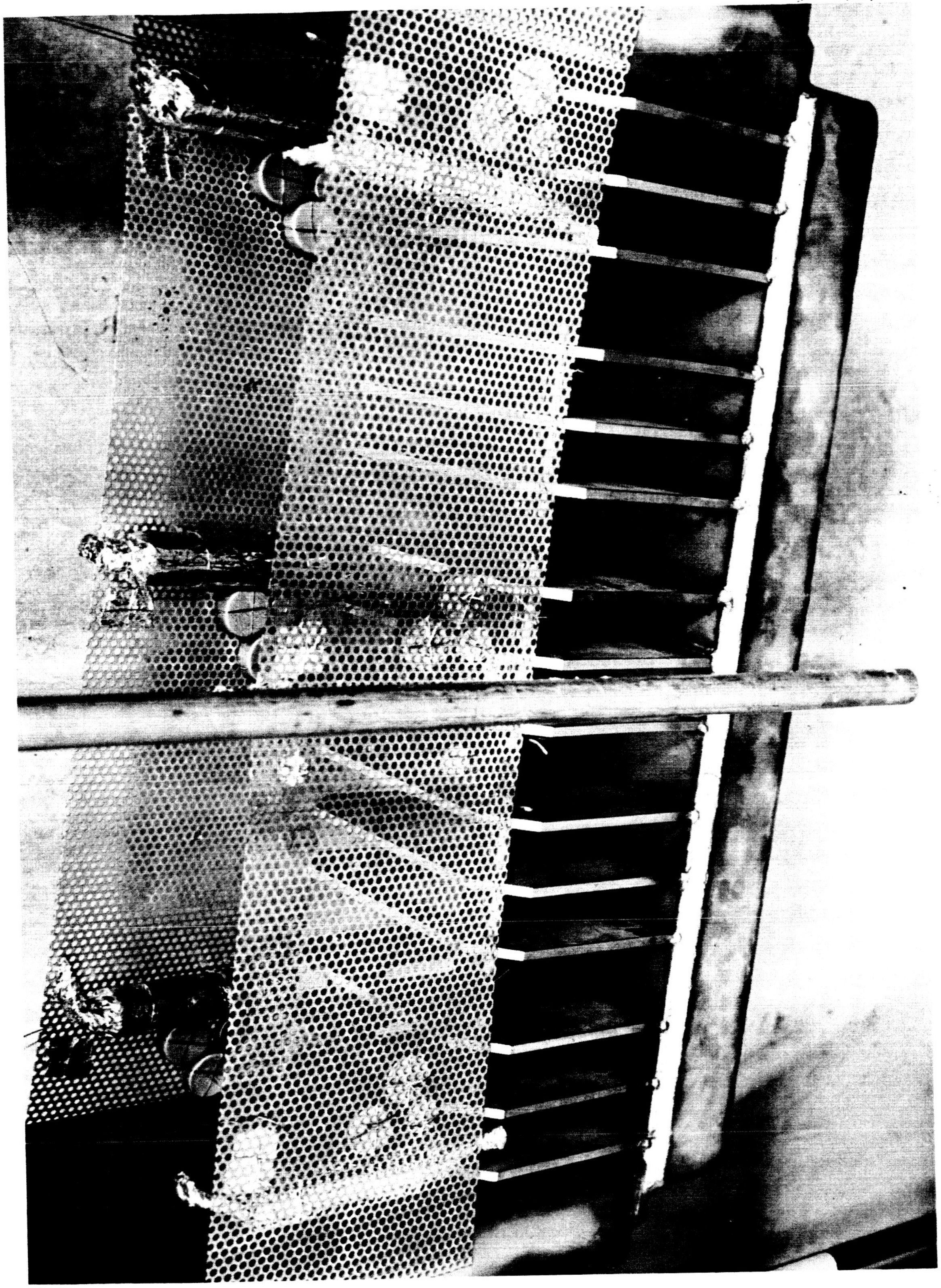

Figure 5.14 Mapping Dosimetry Mounted on Experimental Assembly

neutron flux for E > 2.9 Mev, one aluminum foil to measure the neutron flux for E > 8.1 Mev, and one nitrous-oxide dosimeter to measure the gamma dose. In addition to the above packets (which were inside the dewar during the run), packets consisting of one gamma dosimeter, one thermal detector, and one fast-neutron (E > 2.9 Mev) detector were mounted on the outside surfaces (front and back) of the dewars. These packets were positioned at the center of the dewar, just opposite a corresponding packet at rods 3 and 8 inside the dewar.

In the first run, the east dewar was filled with water and the north dewar contained static air at atmospheric pressure and ambient temperature. In the second run, the north dewar (which used the same dosimetry layout as described above) was filled with liquid nitrogen.

Past experience with dosimetry measurements on the GTR has established the reliability of using a definite ratio of east-to-west and east- or west-to-north dose rates in air at given distances from the reactor face on the core centerline. For fast neutrons (E > 2.9 Mev), the east-to-west ratio is 1:1 and the east- or west-to-north ratio is 1:1.7. For gamma radiation, the east-to-west ratio is 1:1 and the east- or west-to-north ratio is 1:1.2. Reliability of these values is considered to be well within the limits of reproducibility of successive measurements for both neutrons and gamma rays. The north-to-east or west ratio (1.7:1) is based on a 4-in. thickness of water between the core and the inside face of the closet. This ratio can be increased by moving the reactor north (farther into the closet and closer to the north closet wall), thus reducing the water thickness to 2 in.

With these ratios, and with the data taken on the above-described mapping run, it is possible to determine both the neutron and gamma dose rates in the experimental assemblies at all the irradiation positions for all three dewar environments: water, air, and liquid nitrogen. Water was used in the east dewar to simulate the neutron attenuation that would take place in liquid hydrogen, and data from the dosimetry are considered suitable for predicting dose rates in an LH_2-filled dewar. The usual environment in the dewars for irradiations at NARF is either air, LN_2, or LH_2.

Data from the mapping runs are shown in Tables 5.1 through 5.3 and are plotted in Figures 5.15 through 5.20.

Figures 5.15 through 5.17 are plots of the neutron fluxes for the three environments. Fast fluxes in the east, west, or north dewar for any of the three environments can thus be determined either by referring to the appropriate curves or by multiplying or dividing a particular data point on a curve by the factor 1.7.

Figures 5.18 through 5.20 are plots of gamma dose rates for the three environments. Like the above-described approach for neutron fluxes, the gamma dose rates in the east, west, or north dewar for any of the three environments can be determined either by reference to the appropriate curve or by calculation. Gamma dose rates for a particular environment and irradiation position not used in the mapping runs can be determined by multiplying or dividing a particular recorded data point by the factor 1.2.

No radical departures from anticipated neutron-flux values are indicated in Figures 5.15 through 5.17. The high thermalizing effect of water can be noted in data taken from the water-filled dewar. The curves in Figures 5.16 and 5.17 indicate nothing more than the normally expected mass and distance attenuation of neutron fluxes, thus denoting little or no low-temperature effects on neutron dosimetry in the LN_2-filled dewar.

Gamma dose-rate data recorded in the mapping runs were reasonable and generally in accordance with expectations. As anticipated, reaction of the N_2O gamma dosimeters irradiated while submerged in LN_2 was erratic. This is indicated in Figure 5.20. Based on the gamma dose rates recorded for the front and rear outside faces of the dewar and the dose-rate curve for the air-filled north dewar, the curve considered to be correct for the dose rate along the centerline of the LN_2-filled dewar was drawn on Figure 5.20 as a dashed line. These values will be used in determining specimen locations for future LN_2 irradiations until gamma dosimetry suitable for use at cryotemperatures has been developed.

Table 5.1

Experimental-Assembly Mapping Run: East Dewar, H_2O-Filled

Dosimeter Location		Neutron Flux (n/cm^2-sec-watt)				Gamma Dose Rate [ergs/gm(C)-hr-watt]
		E<0.48 ev	E>0.85 Mev	E>2.9 Mev	E>8.1 Mev	
Outside Front Face of Dewar	Front of Rod 1	-	-	-	-	-
	Front of Rod 3	1.10(4)	-	4.09(4)	-	9.5(2)
	Front of Rod 5	-	-	-	-	-
Inside of Dewar	At Rod 1	6.89(4)	2.22(4)	1.06(4)	4.22(2)	2.8(2)
	At Rod 3	1.17(5)	3.86(4)	1.51(4)	5.85(2)	3.9(2)
	At Rod 5	6.98(4)	2.84(4)	1.18(4)	4.73(2)	4.0(2)
Inside of Dewar	At Rod 6	1.65(4)	2.86(3)	1.19(3)	1.29(2)	1.3(2)
	At Rod 8	2.19(4)	3.19(3)	1.74(3)	1.13(2)	1.8(2)
	At Rod 10	1.40(4)	3.42(3)	1.42(3)	9.57(1)	1.3(2)
Outside Back Face of Dewar	Back of Rod 6	-	-	-	-	-
	Back of Rod 8	1.13(3)	-	3.19(2)	-	9.0(1)
	Back of Rod 10	-	-	-	-	-

Table 5.2

Experimental-Assembly Mapping Run: North Dewar, Air-Filled

Dosimeter Location		Neutron Flux (n/cm^2-sec-watt)				Gamma Dose Rate [ergs/gm(C) -hr-watt]
		$E < 0.48$ ev	$E > 0.85$ Mev	$E > 2.9$ Mev	$E > 9.1$ Mev	
Outside Front Face of Dewar	Front of Rod 1	-	-	-	-	-
	Front of Rod 3	1.83(3)	-	6.26(4)	-	1.2(3)
	Front of Rod 5	-	-	-	-	-
Inside of Dewar	At Rod 1	-	5.99(4)	2.52(4)	9.16(2)	4.7(2)
	At Rod 3	1.65(3)	6.71(4)	2.79(4)	1.03(3)	5.6(2)
	At Rod 5	2.28(3)	5.49(4)	2.30(4)	8.19(2)	4.9(2)
Inside of Dewar	At Rod 6	2.31(3)	1.22(5)	1.55(4)	6.30(2)	3.2(2)
	At Rod 8	2.19(3)	4.87(4)	1.83(4)	7.29(2)	3.4(2)
	At Rod 10	1.86(3)	4.01(4)	1.58(4)	6.08(2)	3.3(2)
Outside Back Face of Dewar	Back of Rod 6	-	-	-	-	-
	Back of Rod 8	2.04(3)	-	8.76(3)	-	1.4(2)
	Back of Rod 10	-	-	-	-	-

Table 5.3

Experimental-Assembly Mapping Run: North Dewar, LN_2-Filled

Dosimeter Location		Neutron Flux (n/cm^2-sec-watt)				Gamma Dose Rate [ergs/gm(C) -hr-watt]
		E<0.48 ev	E>0.85 Mev	E>2.9 Mev	E>8.1 Mev	
Outside Front Face of Dewar	Front of Rod 1	-	-	-	-	-
	Front of Rod 3	4.90(3)	-	6.59(4)	-	1.2(3)
	Front of Rod 5	-	-	-	-	-
Inside of Dewar	At Rod 1	2.46(3)	-	2.60(4)	8.90(2)	1.0(3)
	At Rod 3	3.79(3)	8.10(4)	2.88(4)	9.75(2)	1.6(3)
	At Rod 5	2.59(3)	7.03(4)	2.45(4)	8.90(2)	7.2(2)
Inside of Dewar	At Rod 6	-	3.07(4)	1.03(4)	4.00(2)	6.8(2)
	At Rod 8	1.70(3)	3.76(4)	1.31(4)	5.08(2)	3.9(2)
	At Rod 10	1.07(3)	-	1.03(4)	4.01(2)	2.4(2)
Outside Back Face of Dewar	Back of Rod 6	-	-	-	-	-
	Back of Rod 8	1.22(3)	-	3.69(3)	-	8.6(1)
	Back of Rod 10	-	-	-	-	-

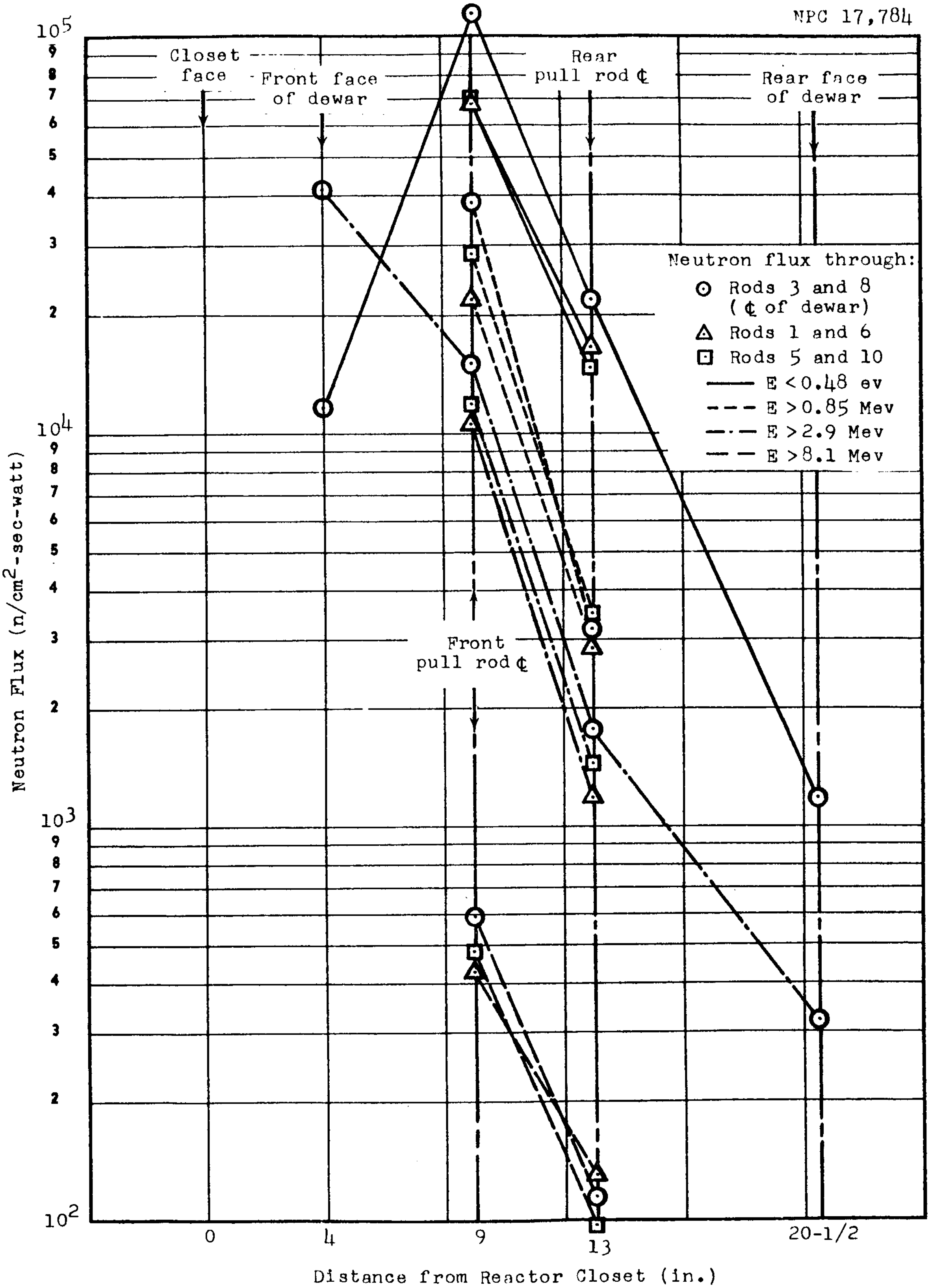

Figure 5.15 Neutron Flux vs Distance from Reactor: East Dewar, H_2O-Filled

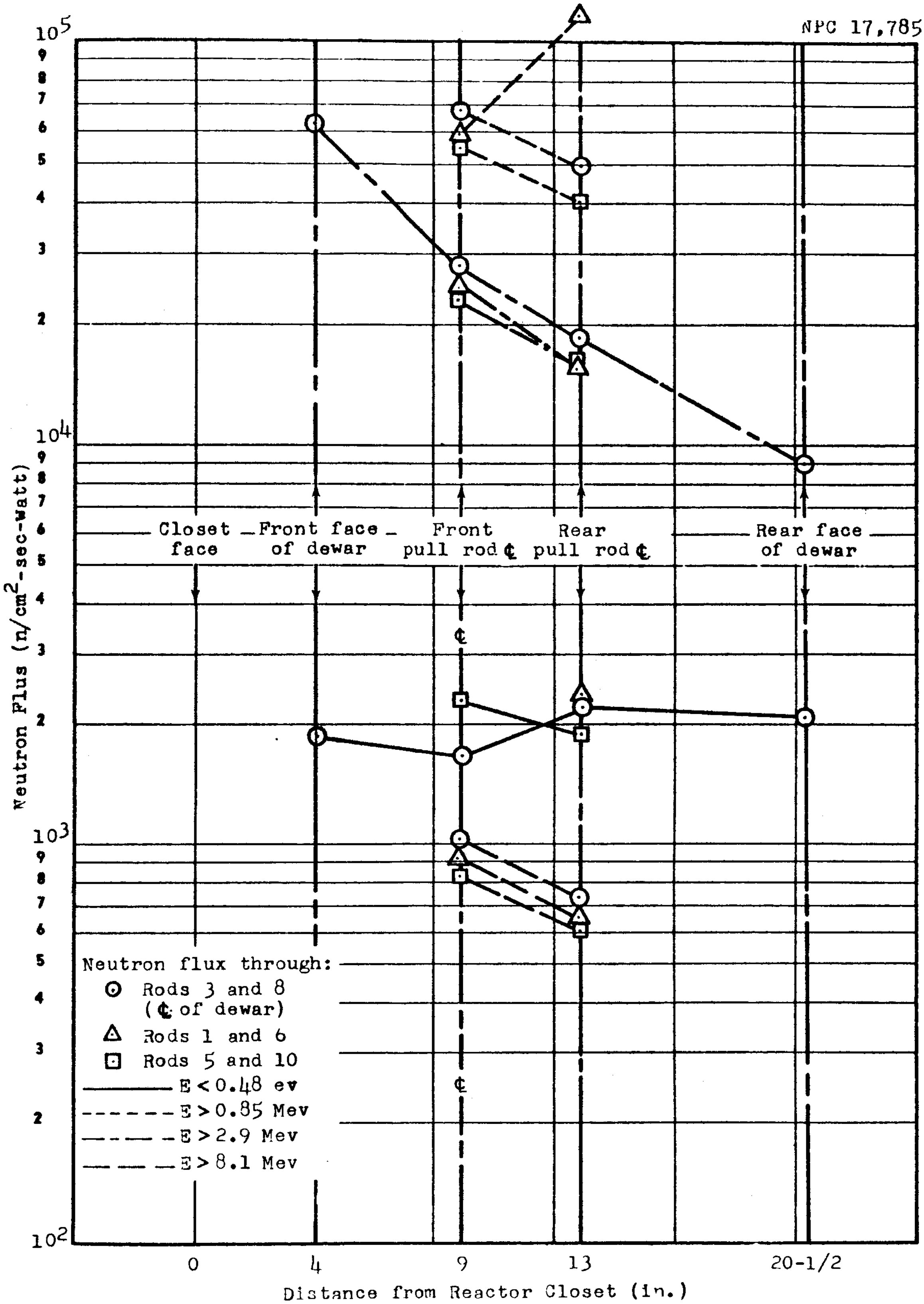

Figure 5.16 Neutron Flux vs Distance from Reactor:
North Dewar, Air-Filled

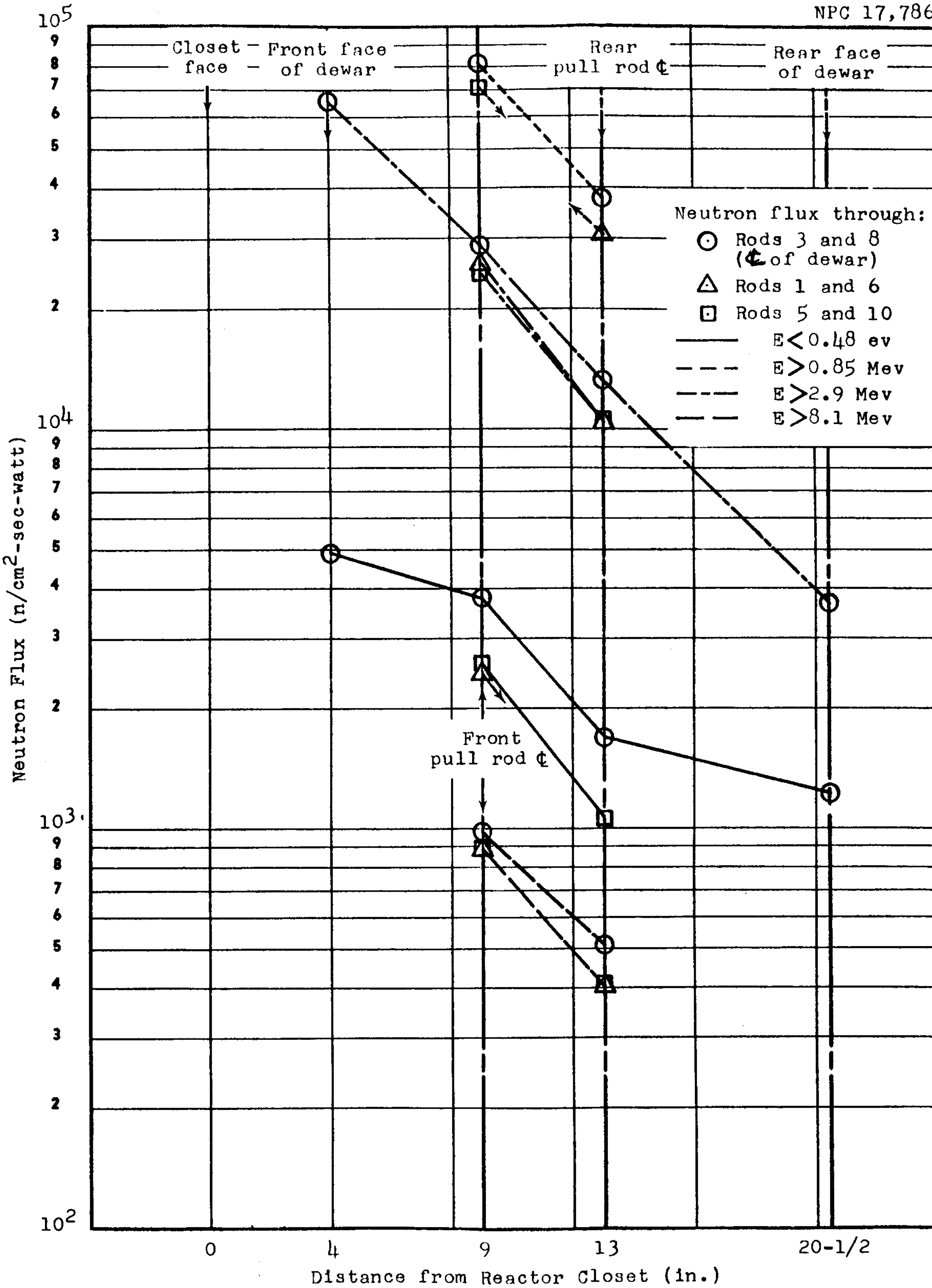

Figure 5.17 Neutron Flux vs Distance from Reactor: North Dewar, LN_2-Filled

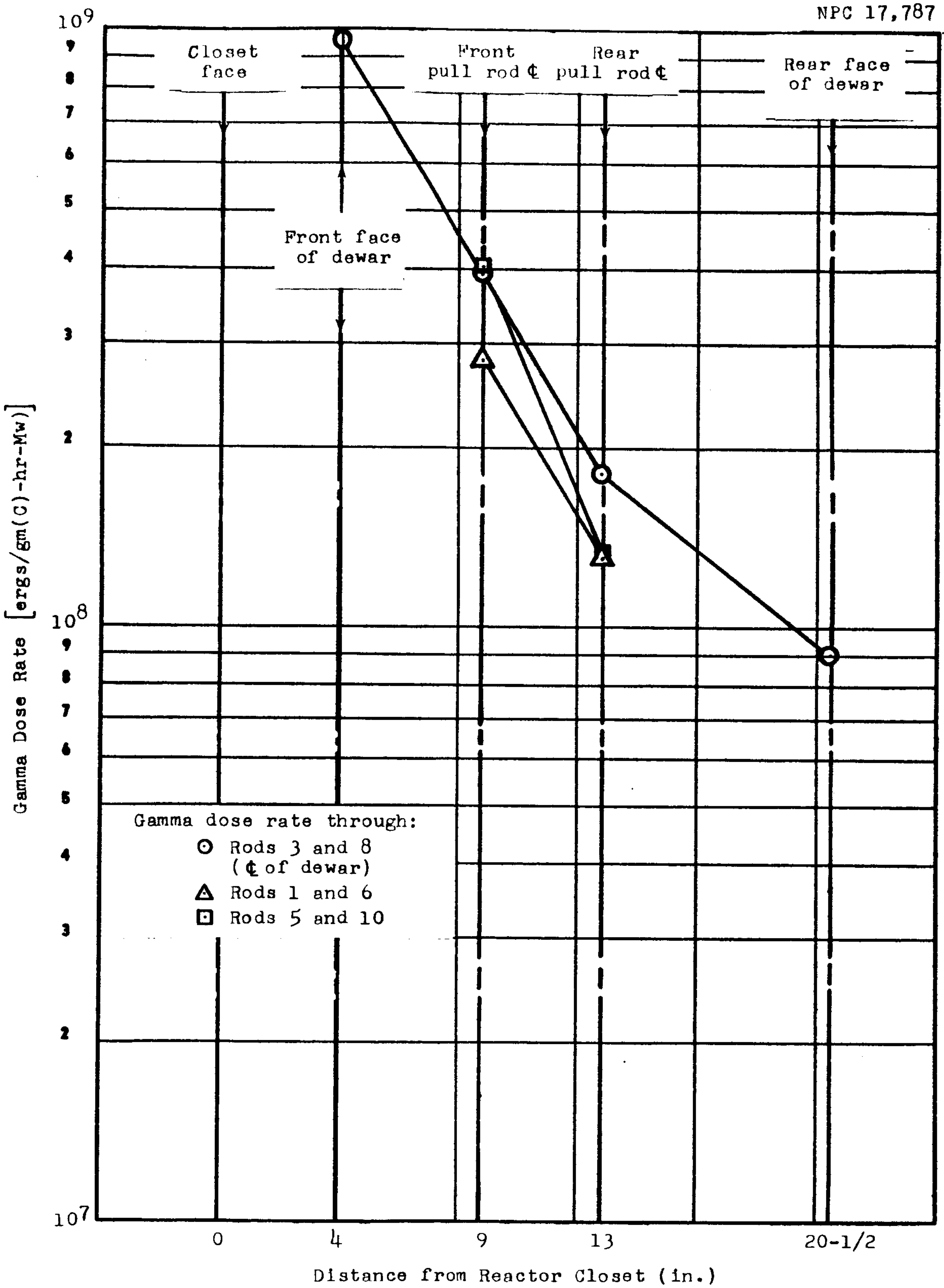

Figure 5.18 Gamma Dose Rate vs Distance from Reactor: East Dewar, H_2O-Filled

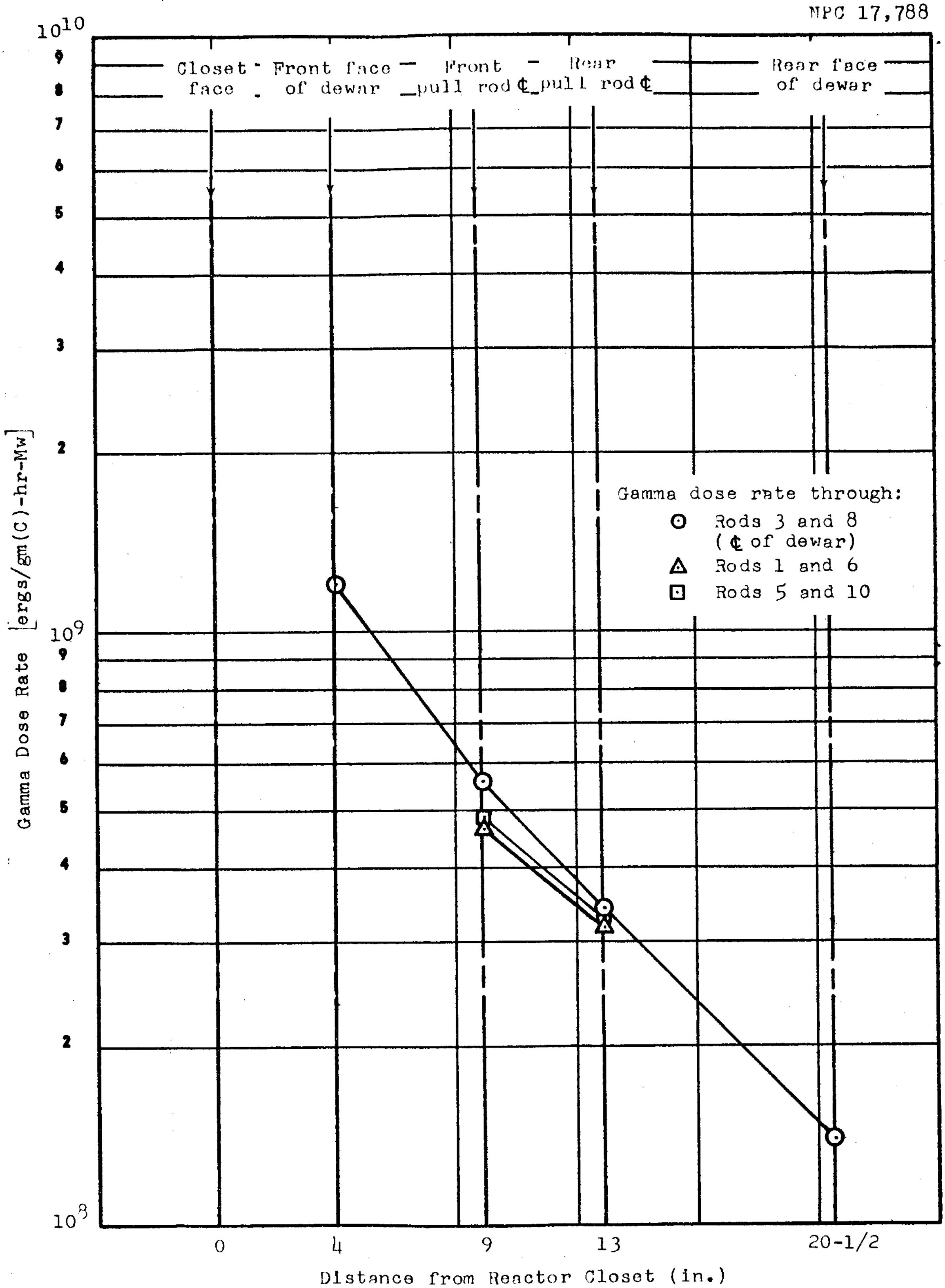

Figure 5.19 Gamma Dose Rate vs Distance from Reactor: North Dewar, Air-Filled

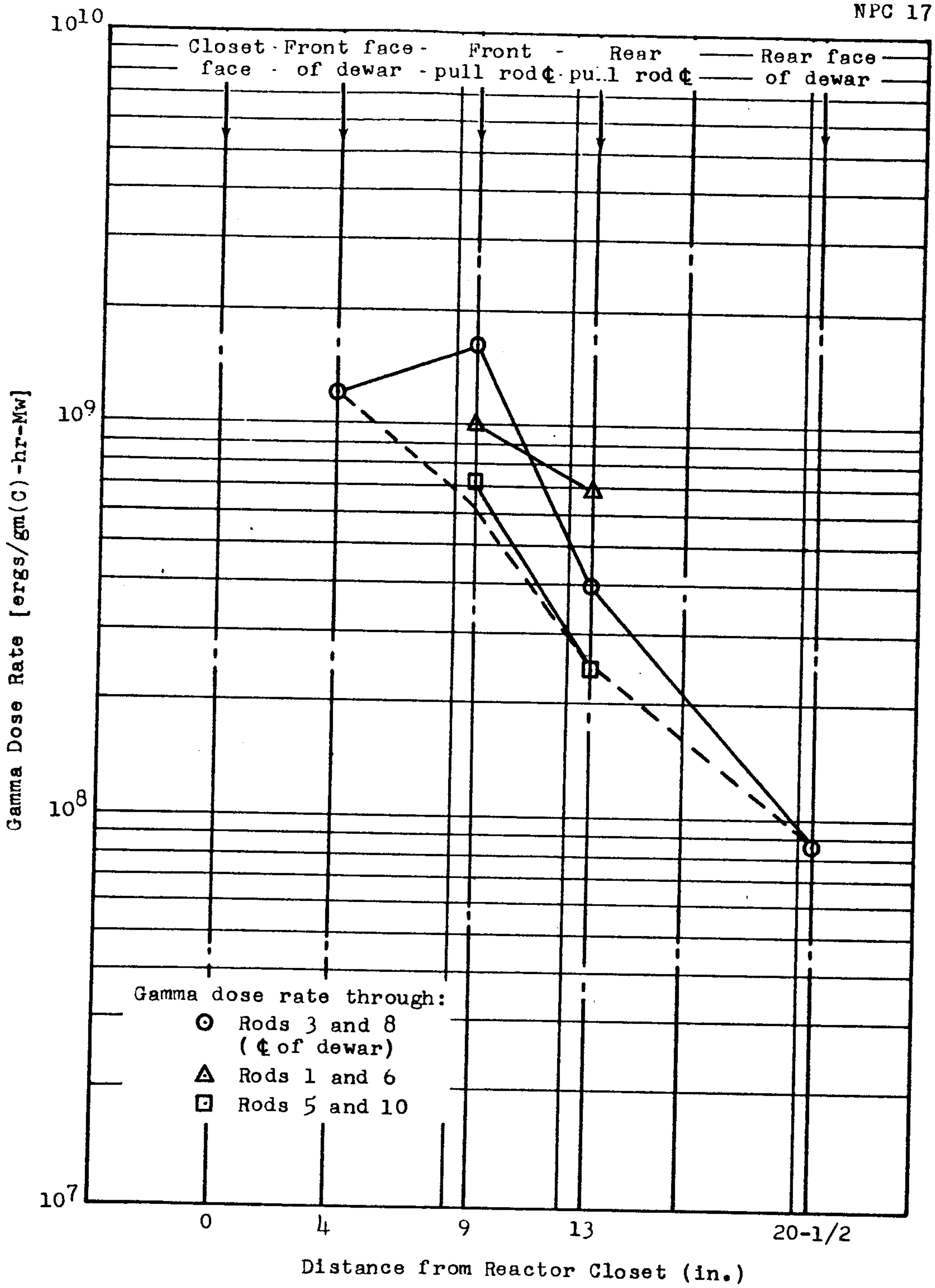

Figure 5.20 Gamma Dose Rate vs Distance from Reactor: North Dewar, LN_2-Filled

VI. MATERIAL TEST RESULTS

The irradiation tests were conducted in the Radiation Effects Testing System at NARF (see Figs. 2.1 and 2.2), with the GTR as the radiation source. All materials scheduled for testing during this reporting period were received and tested at the prescribed low and high dose in both an ambient-air and a liquid-nitrogen environment. For ready reference, the locations of the tabulated data, property curves, and specimen photographs are listed in Table 6.1.

For the ambient-air temperature tests, specimens were mounted on expanded-metal trays as shown in Figures 6.1, 6.2, and 6.3 (April irradiation). The required gamma dose in ergs/gm(C), shown in the upper right hand corner of the photographs, was obtained by judicious placement of the expanded metal trays and by removing the different trays from the radiation field at specified times. The high-dose tray, for instance, required an irradiation time of 33 hr, with the reactor operating at a power level of 3 Mw.

Table 6.2 gives the specimen location, irradiation time, and gamma exposure for the April ambient-air run, but the values are representative of the May and September runs also. Thermocouples were mounted on specimens in the different trays to measure the temperature range of the specimens during irradiation. The average ambient-air temperature ranged from 90° to 110°F. Postirradiation ambient-air tests were conducted in the IML, with the specimens mounted directly in the Instron machine.

Table 6.1

Location of Specimen Photographs and Test Results

Material Category	Code	Material	Tables	Figures			
				Meas. Property* vs Gamma Dose	Ult. Elong. vs Gamma Dose	Stress vs Strain	Photographs
Adhesives (Sec. 6.1)	A	Scotchweld AF-40	B-1	6.6 UTSS	-	-	6.31
	B	Aerobond 422J	B-2	6.7 UTSS	-	-	6.31
Seals (Sec. 6.2)	C	Viton O-Rings	-	-	-	-	6.8
	D	Polymer-SP	B-3,4,5	6.9 UTS	6.10	-	6.11
Electrical Insulation (Sec. 6.3)	H	Geon 8800	B-6,7,8	6.12 UTS	6.13	-	6.14
	I	Duroid 5600	B-9,10, 11	6.15 UTS	6.16	-	6.17
Laminates (Sec. 6.4)	J	Lamicoid 6038E	B-12,13, 14	6.18 UTS	6.19	E-1,E-2,E-3,E-4, E-5,E-6	6.20
	K	CTL-91LD	B-15,16, 17	6.21 UTS	6.22	E-7,E-8,E-9,E-10,E-11,E-12	6.23

Table 6.1 (cont'd)

Material Category	Code	Material	Tables	Figures			
				Meas. Property* vs Gamma Dose	Ult. Elong. vs Gamma Dose	Stress vs Strain	Photographs
Laminates (cont'd)	L	DC-2104	B-18,19, 20	6.24 UTS	6.25	E-13,E-14,E-15, E-16,E-17,E-18	6.26
Dielectrics (Sec. 6.5)	Q	Teflon TFE-7	B-21	6.27 UTS	6.28	-	6.29
Potting Compounds (Sec. 6.6)	M	Epon 828/Z	B-22	6.30 PWPL	-	-	6.31
	N	EC-2273B/A	B-23,24	6.32 PWPL	-	-	6.31
Sealants (Sec. 6.7)	O	EC-1949	B-25,26	6.33 TPS	-	-	6.31
	P	EC-1663	B-27,28	6.34 TPS	-	-	6.31
Thermal Insulations (Sec. 6.8)	E	Stafoam AA-402	-	-	-	-	3.6
	F	CPR-20-2	6.5	6.35 k	-	-	3.9
	G	CPR-1021-2	6.6	6.36 k			3.9

*UTSS - Ultimate Tensile Shear Strength (psi)
UTS - Ultimate Tensile Strength (psi)
k - Coefficient of Thermal Conductivity (Btu-in./hr-ft^2-^oF)
PWPL - Potted-Wire Pull-Out Load (lb)
TPS - T-Peel Strength (lb/in. width)

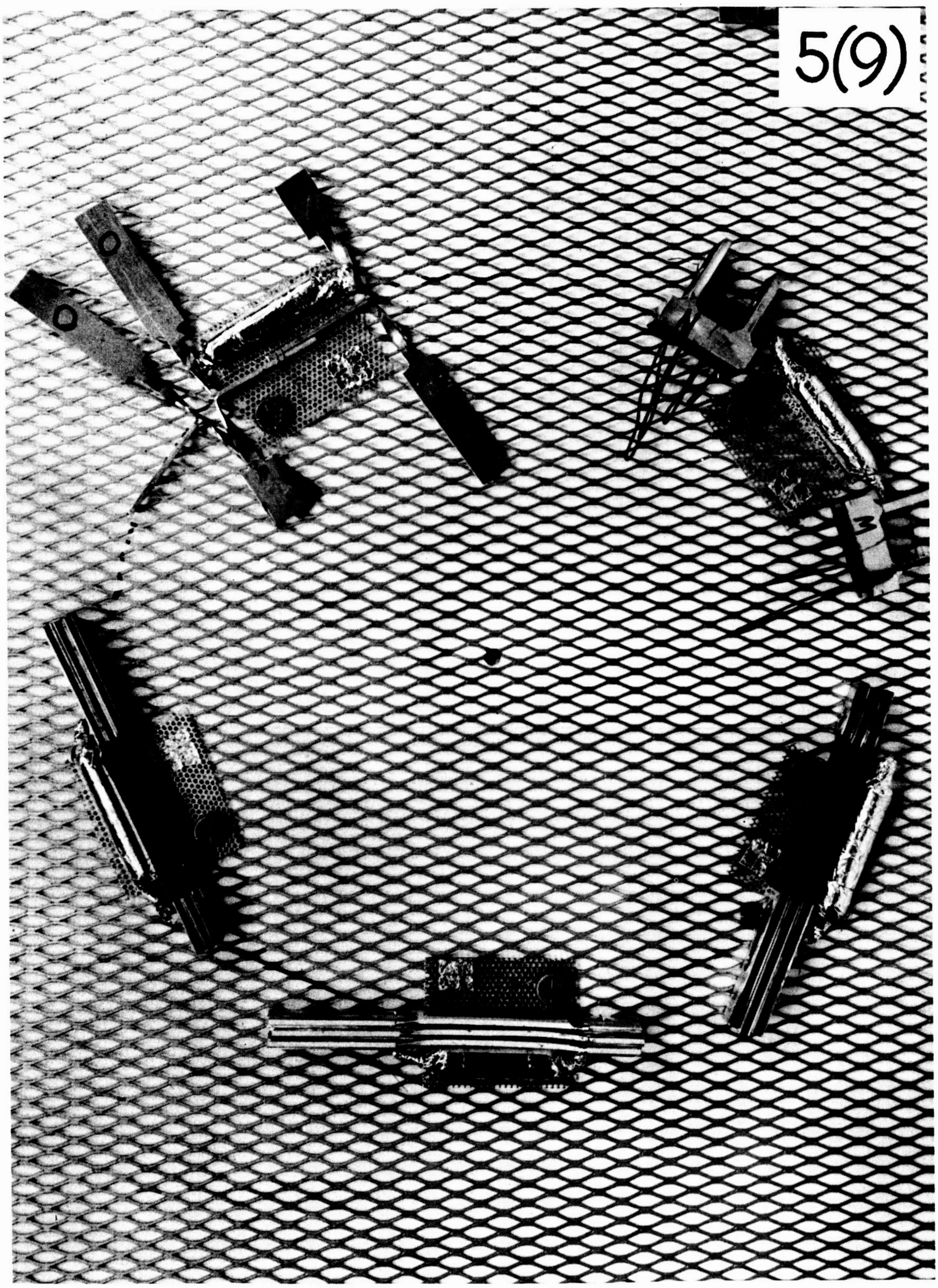

Figure 6.1 Specimen Mounting Arrangement for Ambient-Air Irradiation: Low Dose

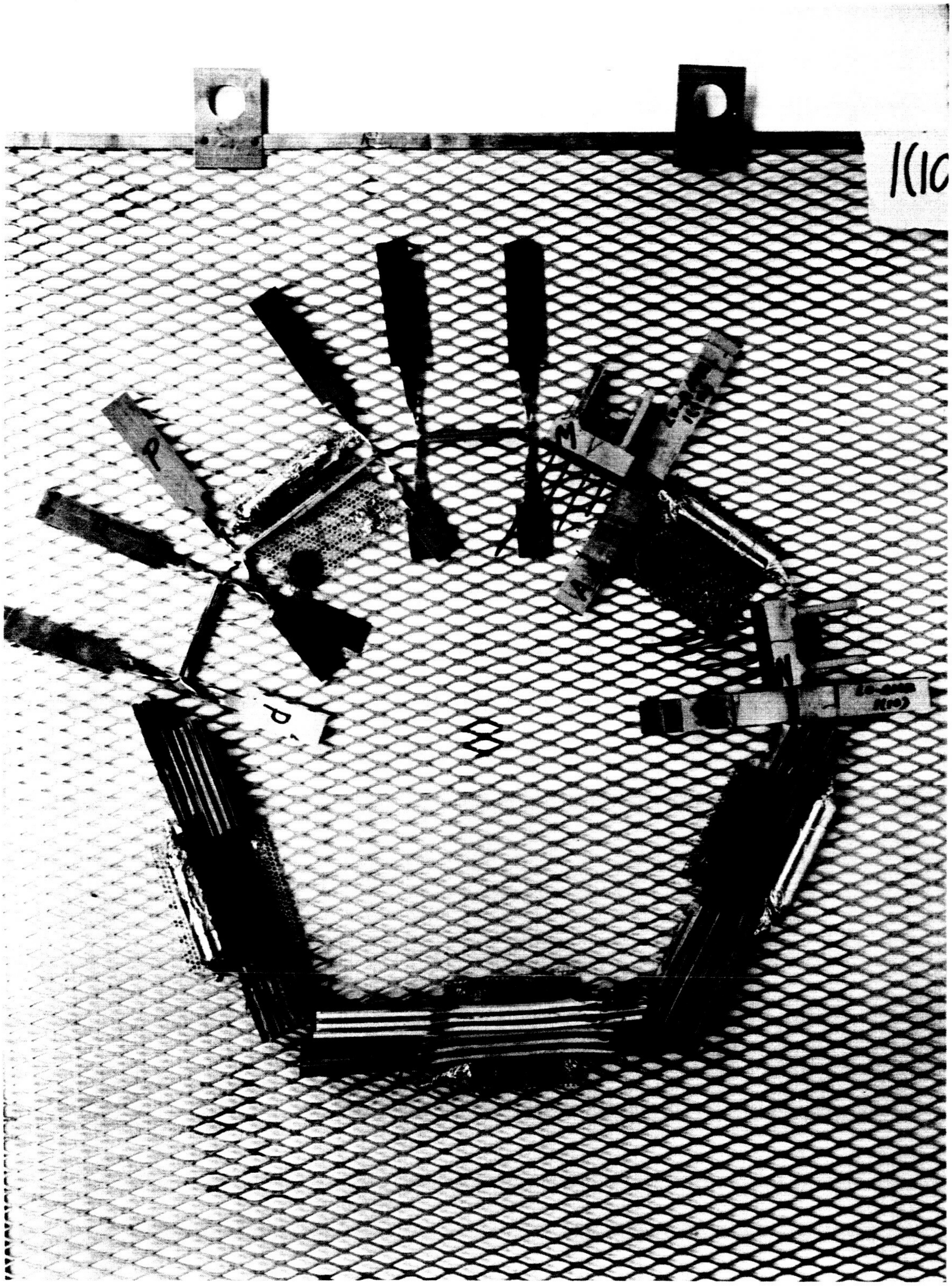

Figure 6.2 Specimen Mounting Arrangement for Ambient-Air Irradiation: Intermediate Dose

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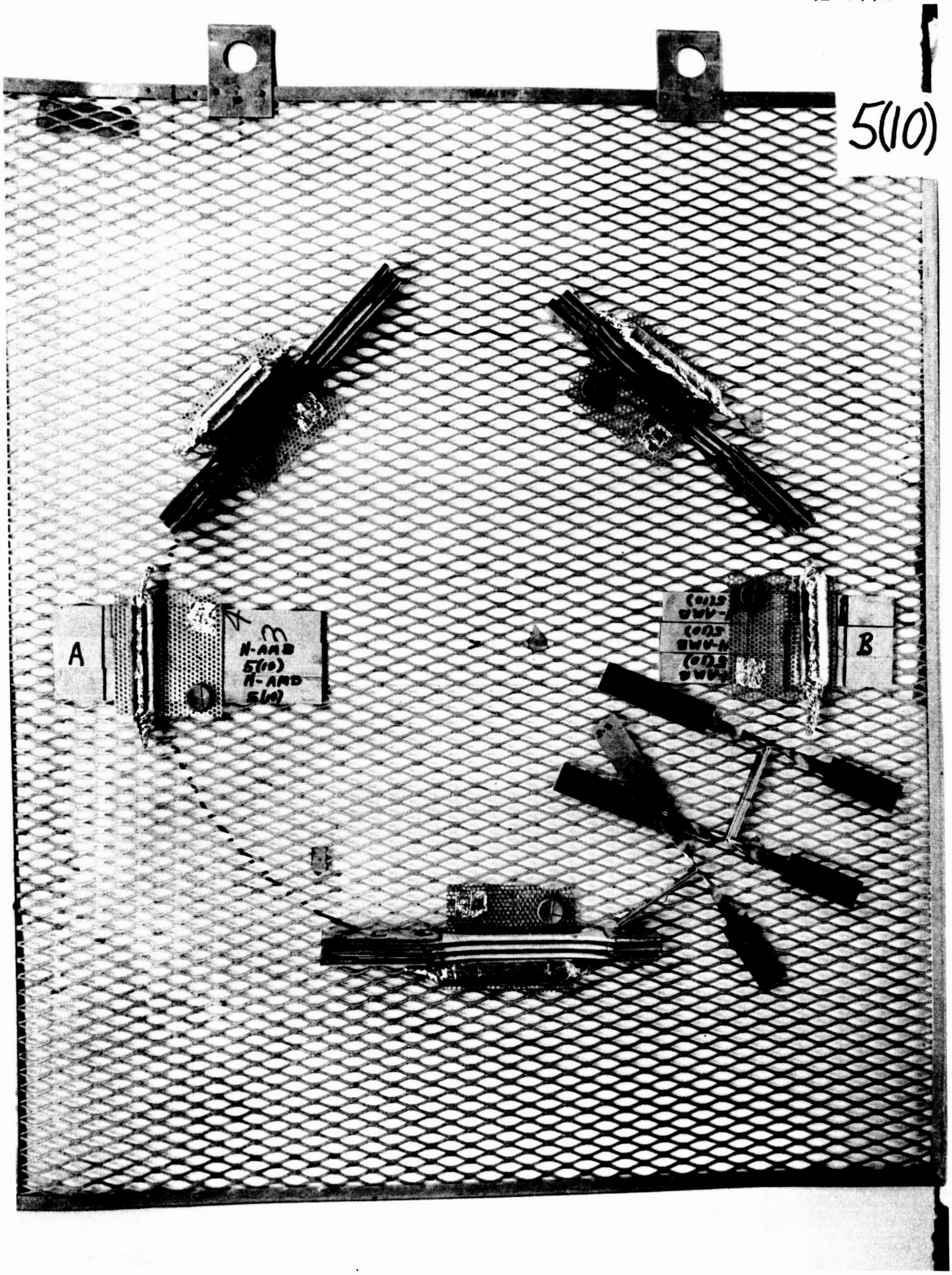


Figure 6.3 Specimen Mounting Arrangement for Ambient-Air Irradiation: High Dose

Table 6.2

Specimen Location and Radiation Exposure: Ambient-Air Irradiation*; North Position (April Run)

Rack No.	Gamma Dose [ergs/gm(C)]	Gamma Dose Rate [ergs/gm(C)-hr-3 Mw]	Length of Irradiation (hr)	Distance of Tray from Front of Frame (in.)	Specimen Mounting Radius (in.)
1	5×10^9	1.02×10^9	4.9	10	10
2	1×10^{10}	9.27×10^8	10.8	12	9
3	5×10^{10}	1.51×10^9	33.02	2.25	10

*Four inches of H_2O between reactor core and closet face.

For the low-dose LN_2 irradiation in April, specimens were mounted in the west experimental assembly as shown in Figures 6.4 and 6.5. The same general specimen arrangement was used for the LN_2 control specimens and for the September high- and low-dose LN_2 irradiations. Details of the specimen layout, the gamma dose, and the irradiation times for each material are given in Table 6.3 for the April run. After each successive period of irradiation, the reactor was shut down and the specimens pulled in tension while still submerged in the liquid nitrogen. The postirradiation LN_2 tests were conducted with the cryogenic experimental assembly, the Instron machine, and the interconnecting hydraulic servo-system.

The effects of radiation on the material properties at both ambient-air and LN_2 temperatures are summarized in Table 6.4. These effects are expressed as a percent change after irradiation

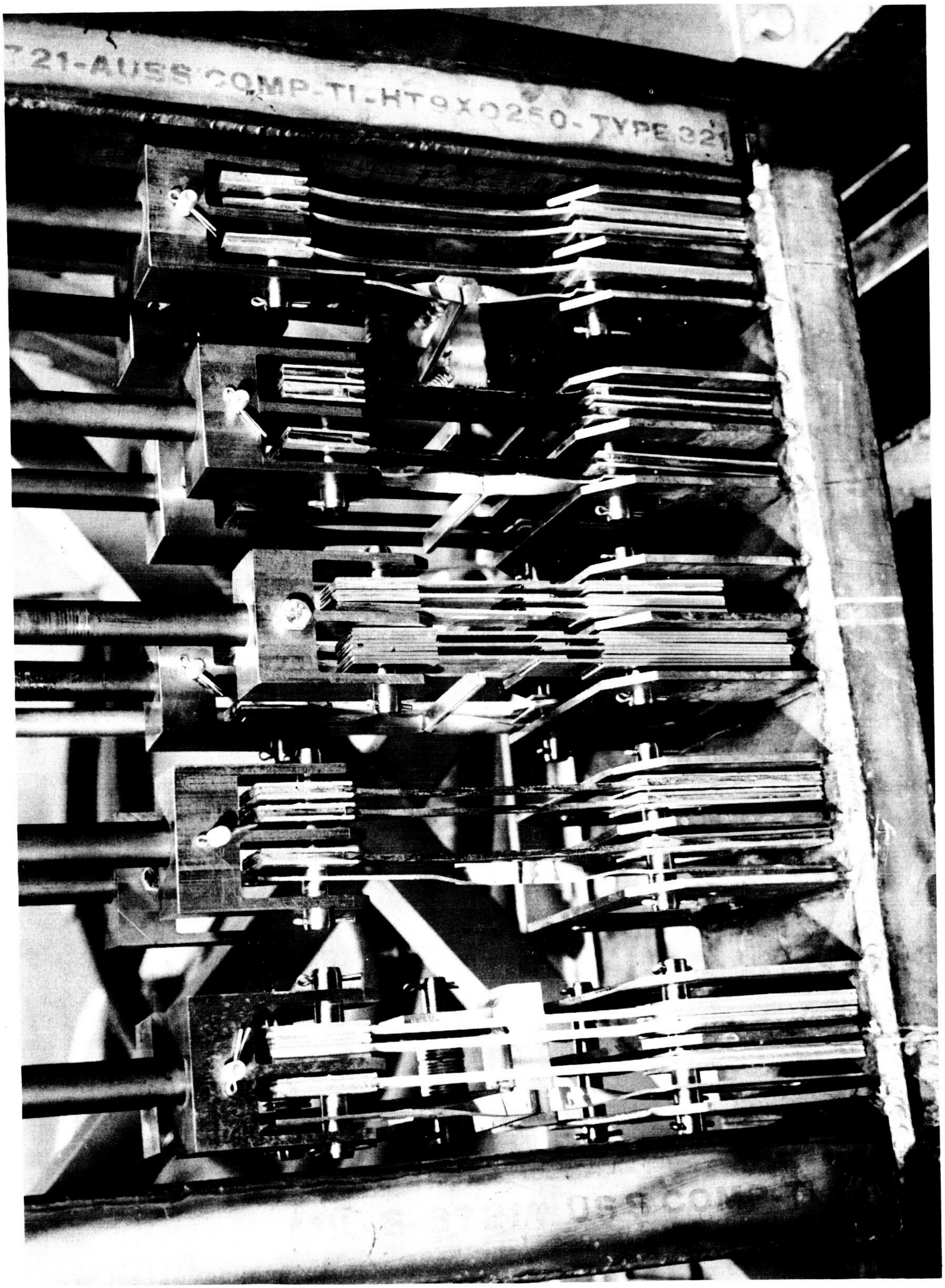


Figure 6.4 Specimen Mounting Arrangement for LN_2 Irradiation: Low Dose, Reactor Side

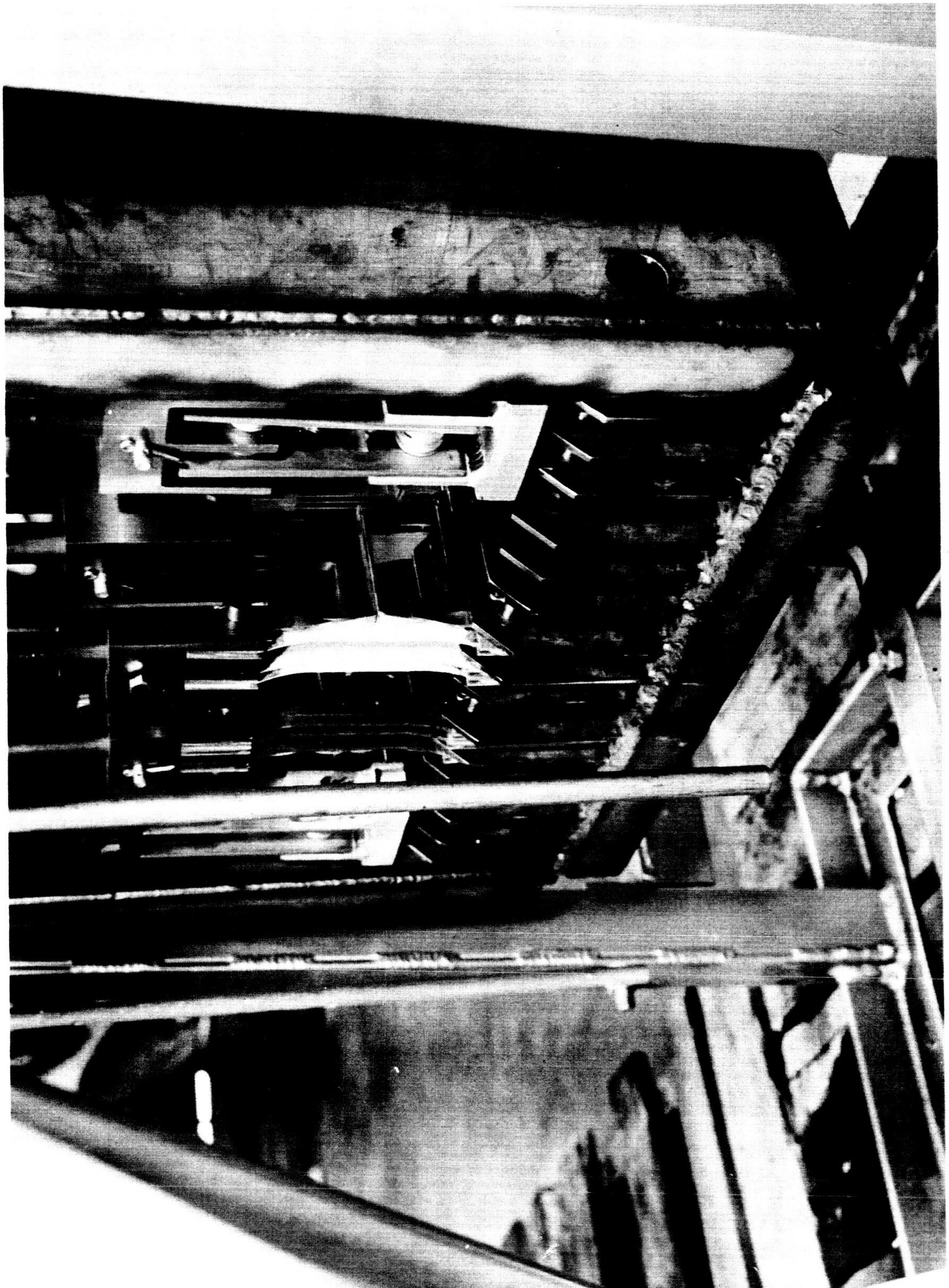


Figure 6.5 Specimen Mounting Arrangement for LN_2 Irradiation:
Low Dose, Back Side

Table 6.3

Specimen Location and Radiation Exposure:
Low-Dose LN_2 Irradiation; West Dewar
(April Run)

Rod 10 Material N (4) 1.6×10^8 ergs/gm(C)-hr-Mw 10.4-hr irradiation	Rod 9 - - 1.85×10^8 ergs/gm(C)-hr-Mw - -	Rod 8 Material H (3) Material O (1) 2.1×10^8 ergs/gm(C)-hr-Mw 7.94-hr irradiation	Rod 7 Material I (3) Material O (1) 1.8×10^8 ergs/gm(C)-hr-Mw 9.27-hr irradiation	Rod 6 Material M (4) 1.5×10^8 ergs/gm(C)-hr-Mw 11.1-hr irradiation
Rod 5 Material L (3) Material P (1) 3.5×10^8 ergs/gm(C)-hr-Mw 9.5-hr irradiation	Rod 4 Material K (3) Material P (1) 3.55×10^8 ergs/gm(C)-hr-Mw 9.4-hr irradiation	Rod 3 Material A (3) Material B (3) 3.6×10^8 ergs/gm(C)-hr-Mw 9.25-hr irradiation	Rod 2 Material D (3) Material O (1) 3.4×10^8 ergs/gm(C)-hr-Mw 4.9-hr irradiation	Rod 1 Material J (3) Material P (1) 3.2×10^8 ergs/gm(C)-hr-Mw 10.4-hr irradiation

Reactor Side

Table 6.4

Summary of Property Changes for Materials Tested

Material Category	Code	Material	Environment	Average Gamma Dose [ergs/gm(C)]	Specimen Configuration	Measured Property	Percent Change in Measured Property[a]
Adhesives	A	Scotchweld AF-40	Amb. air	1.1(10)	Lap Shear	Ult. Ten. Shear Str.	+10.2
			Amb. air	7.2(10)	Lap Shear	Ult. Ten. Shear Str.	-53.2
			LN_2	1.1(10)	Lap Shear	Ult. Ten. Shear Str.	-33.8
			LN_2	7.1(10)	Lap Shear	Ult. Ten. Shear Str.	-73.2
	B	Aerobond 422J	Amb. air	1.1(10)	Lap Shear	Ult. Ten. Shear Str.	+ 3.9
			Amb. air	7.2(10)	Lap Shear	Ult. Ten. Shear Str.	+ 4.3
			LN_2	1.1(10)	Lap Shear	Ult. Ten. Shear Str.	- 4.0
			LN_2	7.1(10)	Lap Shear	Ult. Ten. Shear Str.	-16.2
Seals	C	Viton O-Rings	-	-	-	No Tabulated Data Obtained	-
	D	Polymer-SP	Amb. air	6.1(9)	Tensile	Ult. Tensile Str.	+ 6.9
						Ult. Elongation	+38.5
			Amb. air	1.4(10)	Tensile	Ult. Tensile Str.	+13.6
						Ult. Elongation	+21.9
			LN_2	5.8(9)	Tensile	Ult. Tensile Str.	- 4.4
						Ult. Elongation	- 3.4
			LN_2	1.4(10)	Tensile	Ult. Tensile Str.	+16.8
						Ult. Elongation	+37.5

[a]Percent change of irradiated specimens relative to unirradiated controls at the same temperature. Check original data for effect of temperature on specimen characteristics.

Table 6.4 (cont'd)

Material Category	Code	Material	Environment	Average Gamma Dose [ergs/gm(C)]	Specimen Configuration	Measured Property	Percent Change in Measured Property[a]
Electrical Insulation	H	Geon 8800	Amb. air	4.2(9)	Tensile	Ult. Tensile Str.	+ 5.7
						Ult. Elongation	-15.8
			Amb. air	7.9(9)	Tensile	Ult. Tensile Str.	-13.0
						Ult. Elongation	-36.0
			LN_2	6.3(9)	Tensile	Ult. Tensile Str.	-19.9
						Ult. Elongation	- 8.5
			LN_2	1.3(10)	Tensile	Ult. Tensile Str.	-11.6
						Ult. Elongation	+ 1.7
	I	Duroid 5600	Amb. air	7.9(9)	Tensile	Ult. Tensile Str.	-72.7
						Ult. Elongation	-29.6
			Amb. air	1.2(10)	Tensile	Ult. Tensile Str.	-78.8
						Ult. Elongation	-31.9
			LN_2	5.9(9)	Tensile	Ult. Tensile Str.	- 3.1
						Ult. Elongation	- 6.9
			LN_2	1.4(10)	Tensile	Ult. Tensile Str.	-18.5
						Ult. Elongation	-20.7
Laminates	J	Lamicoid 6038E	Amb. air	1.1(10)	Tensile	Ult. Tensile Str.	+ 0.4
						Ult. Elongation	+ 8.3
			Amb. air	5.8(10)	Tensile	Ult. Tensile Str.	+ 1.1
						Ult. Elongation	+ 8.3
			LN_2	9.0(9)	Tensile	Ult. Tensile Str.	0
						Ult. Elongation	- 0.1
			LN_2	6.7(10)	Tensile	Ult. Tensile Str.	- 0.9
						Ult. Elongation	-11.0

Table 6.4 (cont'd)

Material Category	Code	Material	Environment	Average Gamma Dose [ergs/gm(C)]	Specimen Configuration	Measured Property	Percent Change in Measured Property[a]
Laminates (cont'd)	K	CTL-91LD	Amb. air	1.1(10)	Tensile	Ult. Tensile Str.	+11.6
						Ult. Elongation	+ 6.1
			Amb. air	3.9(10)	Tensile	Ult. Tensile Str.	+14.7
						Ult. Elongation	+ 4.8
			LN_2	9.3(9)	Tensile	Ult. Tensile Str.	- 1.7
						Ult. Elongation	+ 3.2
			LN_2	6.7(10)	Tensile	Ult. Tensile Str.	-20.8
						Ult. Elongation	-44.8
	L	DC-2104	Amb. air	1.1(10)	Tensile	Ult. Tensile Str.	+20.6
						Ult. Elongation	+15.2
			Amb. air	3.9(10)	Tensile	Ult. Tensile Str.	+33.8
						Ult. Elongation	+26.2
			LN_2	6.5(9)	Tensile	Ult. Tensile Str.	- 2.9
						Ult. Elongation	+ 7.0
			LN_2	6.7(10)	Tensile	Ult. Tensile Str.	+ 1.4
						Ult. Elongation	-14.7
Dielectrics	Q	Teflon TFE-7	LN_2	1.1(8)	Tensile	Ult. Tensile Str.	-20.1
						Ult. Elongation	-57.0
			LN_2	1.1(9)	Tensile	Ult. Tensile Str.	-13.1
						Ult. Elongation	-58.3
Potting Compounds	M	Epon 828/Z	Amb. air	5.4(9)	Wire Pull	Wire Pull-Out Load[b]	- 5.3
			Amb. air	1.1(10)	Wire Pull	Wire Pull-Out Load	- 7.9
			LN_2	3.9(9)	Wire Pull	Wire Pull-Out Load	+64.1
			LN_2	1.3(10)	Wire Pull	Wire Pull-Out Load	-51.3

Table 6.4 (cont'd)

Material Category	Code	Material	Environment	Average Gamma Dose [ergs/gm(C)]	Specimen Configuration	Measured Property	Percent Change in Measured Property[a]
Potting Compounds	N	EC-2273B/A	Amb. air Amb. air	5.4(9) 1.1(10)	Wire Pull Wire Pull	Wire Pull-Out Load[b] Wire Pull-Out Load	-12.8 -34.2
Sealants	O	EC-1949	Amb. air Amb. air	5.8(9) 1.1(10)	T-Peel T-Peel	T-Peel Strength[c] T-Peel Strength	-43.7 -57.6
	P	EC-1663	Amb. air	1.1(10)	T-Peel	T-Peel Strength	-76.5
Thermal Insulations	E	Stafoam AA-402	-	-	-	No Tabulated Data Obtained	-
	F	CPR-20-2	Amb. air LN_2 LN_2	1.0(10) 1.0(9) 1.0(10)	T.C.T.[d] T.C.T. T.C.T.	k[e] k k	+ 5.1 0 + 1.8
	G	CPR-1021-2	Amb. air LN_2 LN_2	1.0(10) 1.0(9) 1.0(10)	T.C.T. T.C.T. T.C.T.	k k k	+25.1 +14.1 +32.0

[b]Load measured in pounds
[c]T-Peel Strength in Pounds Per Inch Width
[d]Thermal Conductivity Tester
[e]Coefficient of Thermal Conductivity in Units of Btu-in./hr-ft^2-^{o}F

relative to the unirradiated control values at the same temperature and test conditions. Information in Table 6.4 should be considered as a guide to the relative changes of the properties measured and not as rigid design criteria. A comparison of the values of the ambient-air and LN_2 controls before irradiation indicates that temperature and test conditions had a marked influence on the ultimate tensile strength and ultimate elongation before any irradiation had taken place.

Pertinent comments on results of the tests for each material are given below. Curves of property change vs gamma dose are shown and specimen photographs are included. The tabulated data and stress-strain curves called out in Table 6.1 are in Appendices B and E, respectively.

6.1 Adhesives

Material A: Scotchweld AF-40 (epoxy-nylon)

A detailed statistical study on the adhesives is in Appendix F. After the high dose in ambient-air, the ultimate tensile shear strength decreased sufficiently to indicate a severe degradation of the epoxy-nylon adhesive. The LN_2 temperature reduced the adhesive strength and irradiation reduced it even further. It is not considered useful at LN_2 temperature after exposure to a radiation dose equivalent to the high dose in these tests, or during exposure to a combination of LN_2 temperature and any dose of radiation. The data are plotted in Figure 6.6.

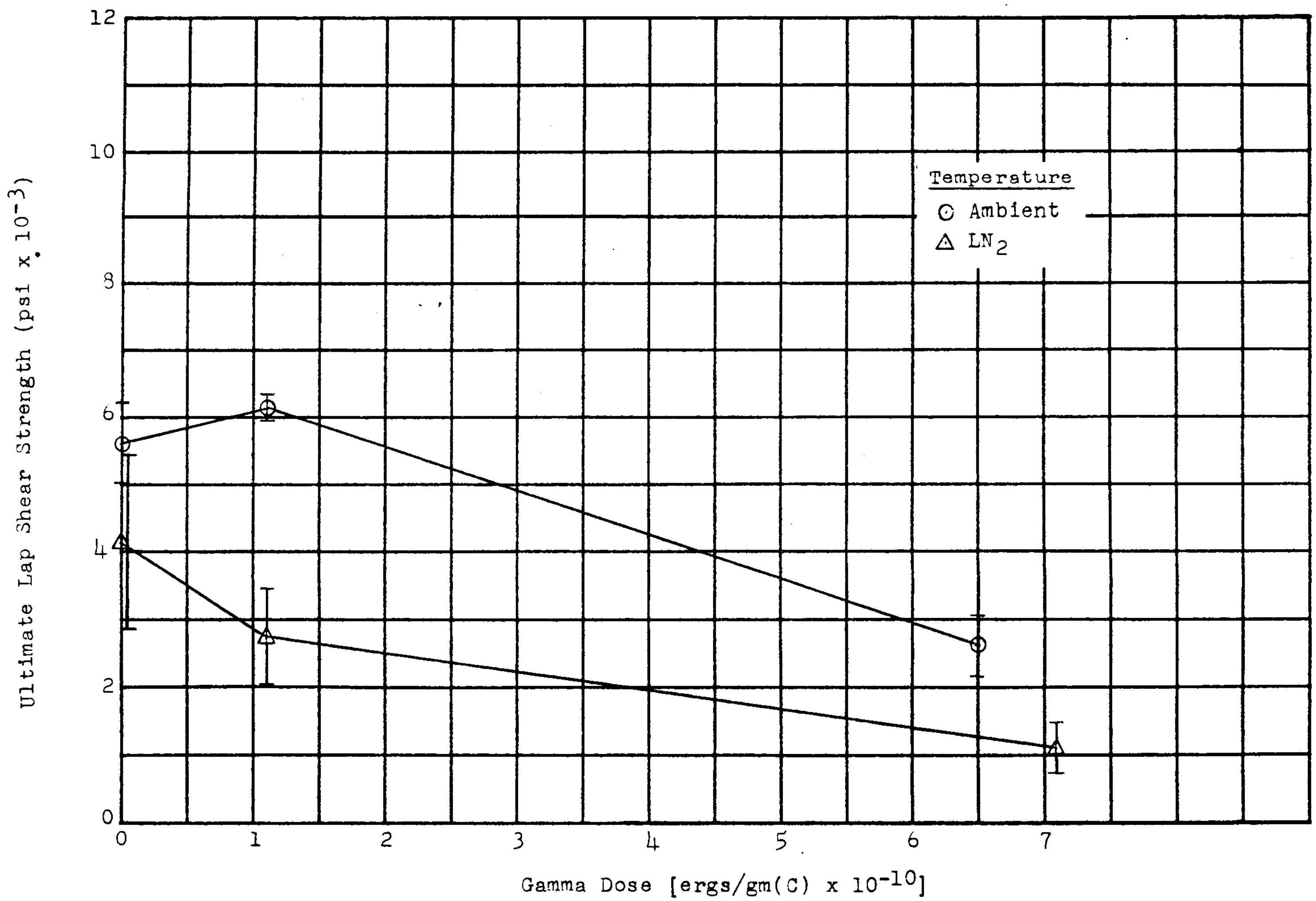


Figure 6.6 Ultimate Tensile Shear Strength vs Gamma Dose: Scotchweld AF-40 (Adhesive A)

Material B: Aerobond 422J (epoxy-phenolic)

This adhesive did not have as high an initial ultimate tensile shear strength as did the Scotchweld AF-40, but it had much better resistance to cryogenic temperatures and radiation. The ambient-air values changed very little with radiation. The LN_2 improved the adhesive strength, and the final tensile shear strength after exposure to the high radiation dose and to LN_2 simultaneously was the same as the initial ambient control value. The data are plotted in Figure 6.7.

6.2 Seals

Material C: Viton O-Ring

Two clean chambers were purged and filled with helium gas under slight pressure, sealed with a Viton-B O-ring, and irradiated for 40 hr in liquid nitrogen to a gamma dose of 1.0×10^{10} ergs/gm(C). The sealed chambers held the original helium gas at room temperature under pressure for six months, from the September 1963 irradiation to March 1964. The chambers were then submerged in water and tested for leakage past the O-ring at a static pressure of 25 psig of helium. Results indicate that Viton-B O-rings provide a good static seal in cryogenic applications in a radiation environment and that further testing is warranted. The test equipment is shown in Figure 6.8.

Material D: Polymer-SP (polypyromellitimide)

The first Polymer-SP dumbbell specimens (wide-gage) did not pull satisfactorily, but after reduction to the narrow-gage cross section, gave satisfactory results in ambient-air and LN_2. When the original specimens were pulled in LN_2, they broke at several

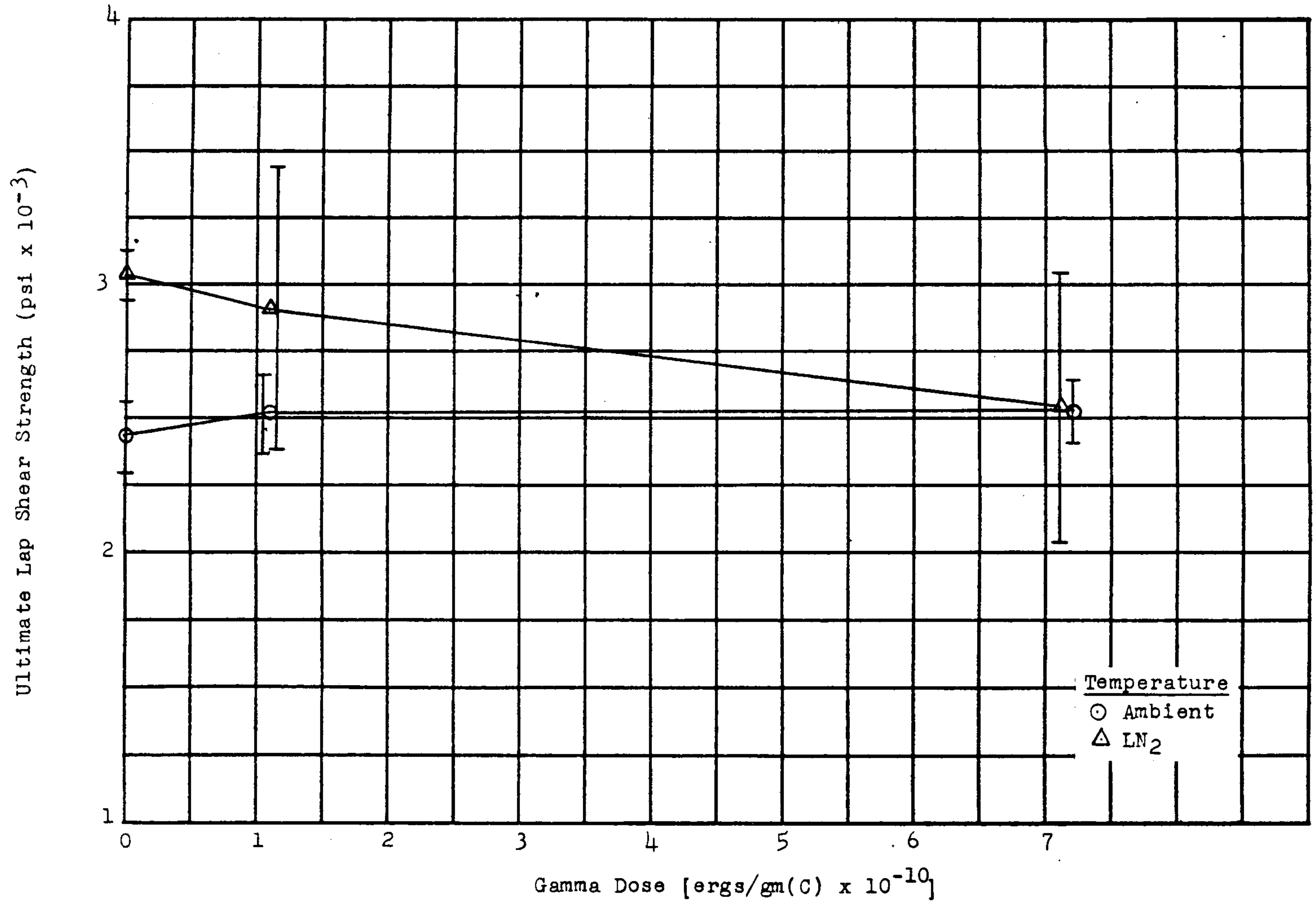


Figure 6.7 Ultimate Tensile Shear Strength vs Gamma Dose: Aerobond 422J (Adhesive B)

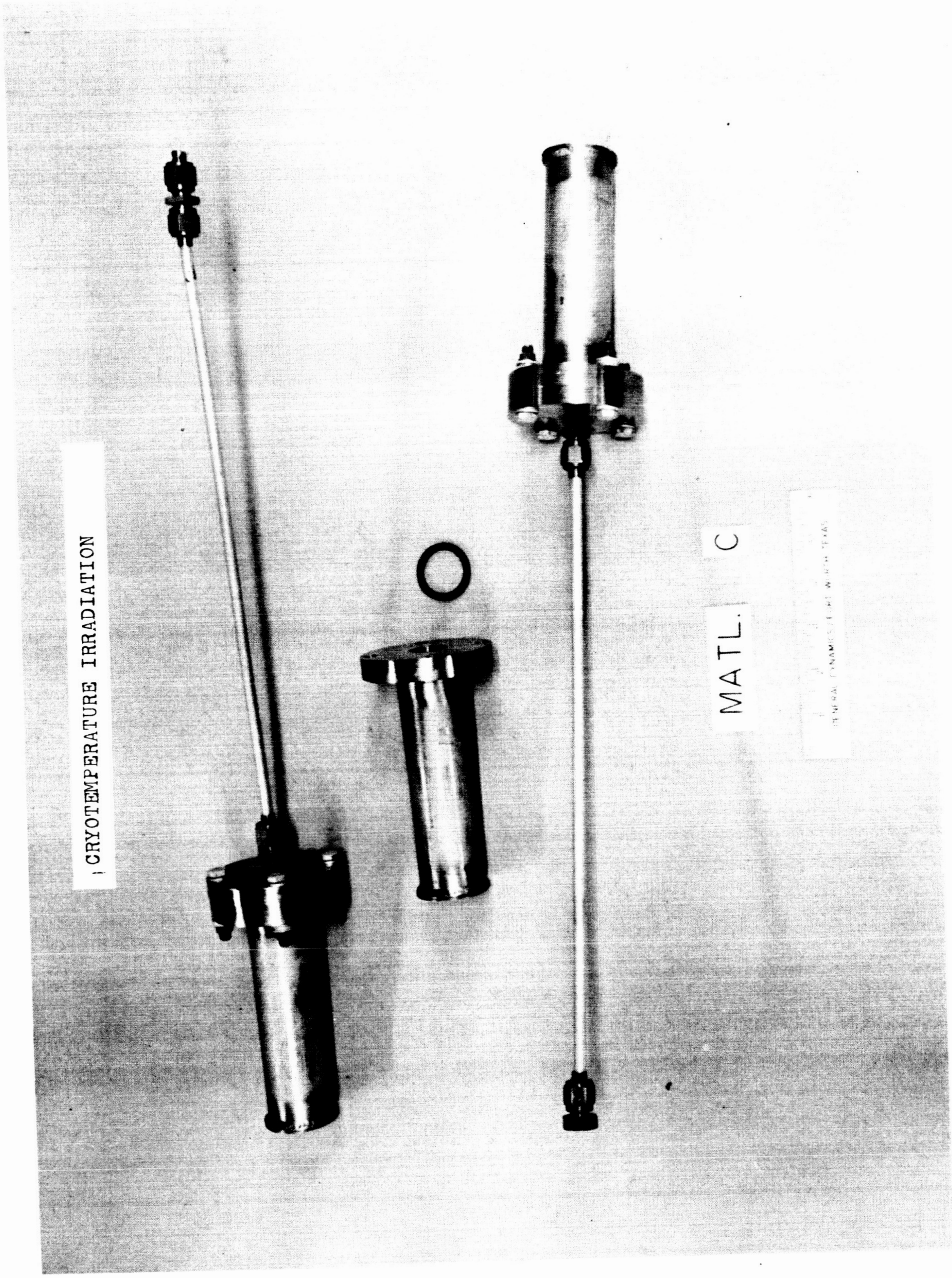


Figure 6.8 Leak Test Chambers and Viton-B O-Ring (Seal C)

places. The tensile data indicated, however, that the specimens first broke in the gage section, then near the doublers as the two halves parted. The specimens were therefore redesigned to have a 1/4-in. gage width in the narrow cross section. Subsequent tests in August and September proved to be satisfactory.

The cryogenic temperature seemed to increase the ultimate tensile strength while causing only a slight decrease in total elongation. Based on the property of ultimate tensile strength, Polymer-SP is considered to have excellent radiation resistance and good cryogenic properties, and should therefore be considered for further testing and space applications. The fundamental causes for the multiple breaks should be given further thought since this problem was not completely resolved. The data are plotted in Figures 6.9 and 6.10. Figure 6.11 is a photograph of Polymer-SP specimens.

6.3 Electrical Insulations

Material H: Geon 8800 (polyvinyl chloride)

This material was tested quite satisfactorily at ambient-air temperature; stress-strain, total elongation, and ultimate tensile strength measurements were obtained. At LN_2 temperature, however, the 1/2-in. gage width specimens shattered between the aluminum doublers during testing. The dumbbell specimens were therefore redesigned to have doublers of Geon and a narrow, 1/4-in. gage width for the rerun tests, but through a misunderstanding, the gage width of those scheduled for the LN_2 irradiations was not changed from the original 1/2-in.

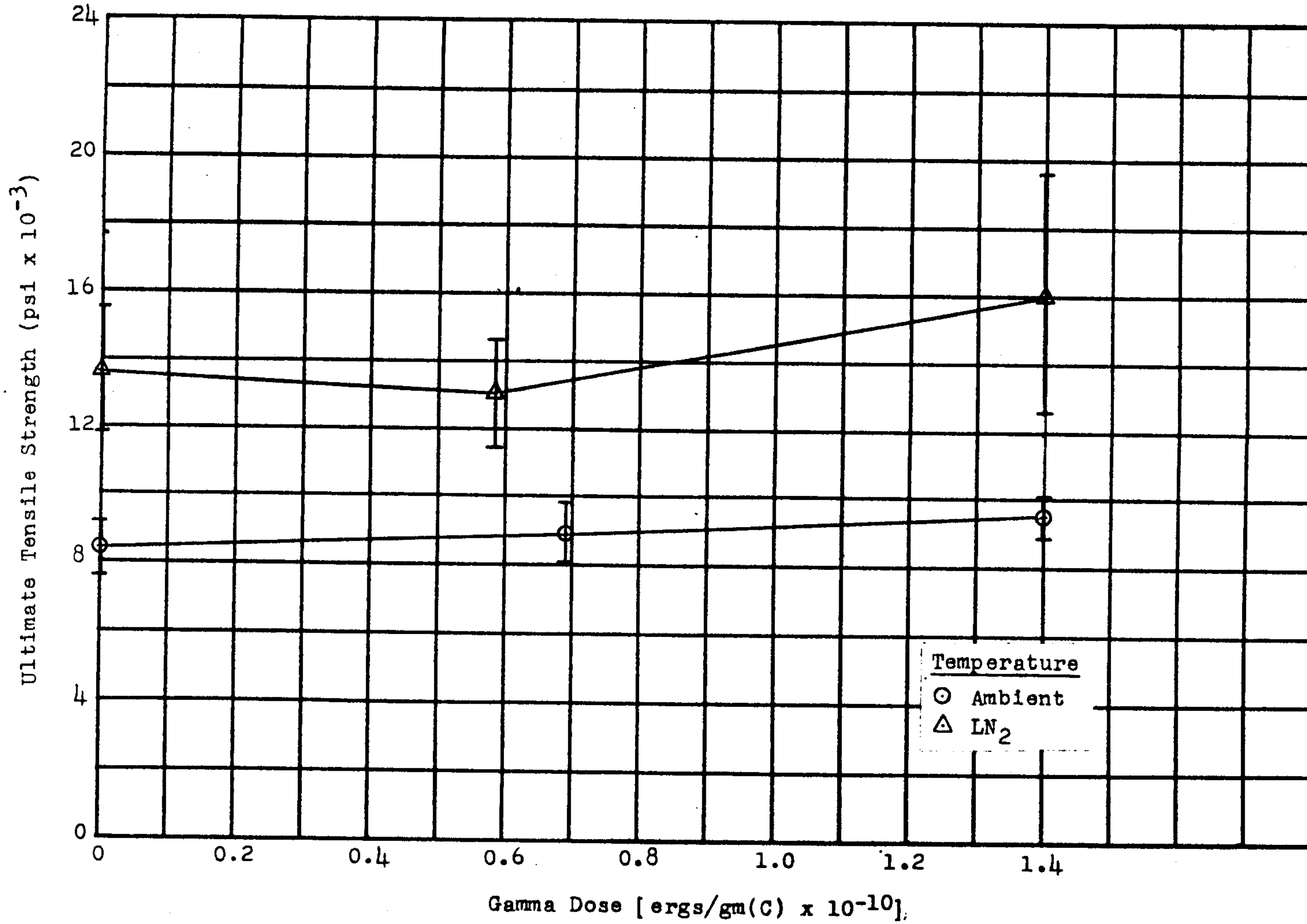


Figure 6.9 Ultimate Tensile Strength vs Gamma Dose: Polymer-SP (Seal D)

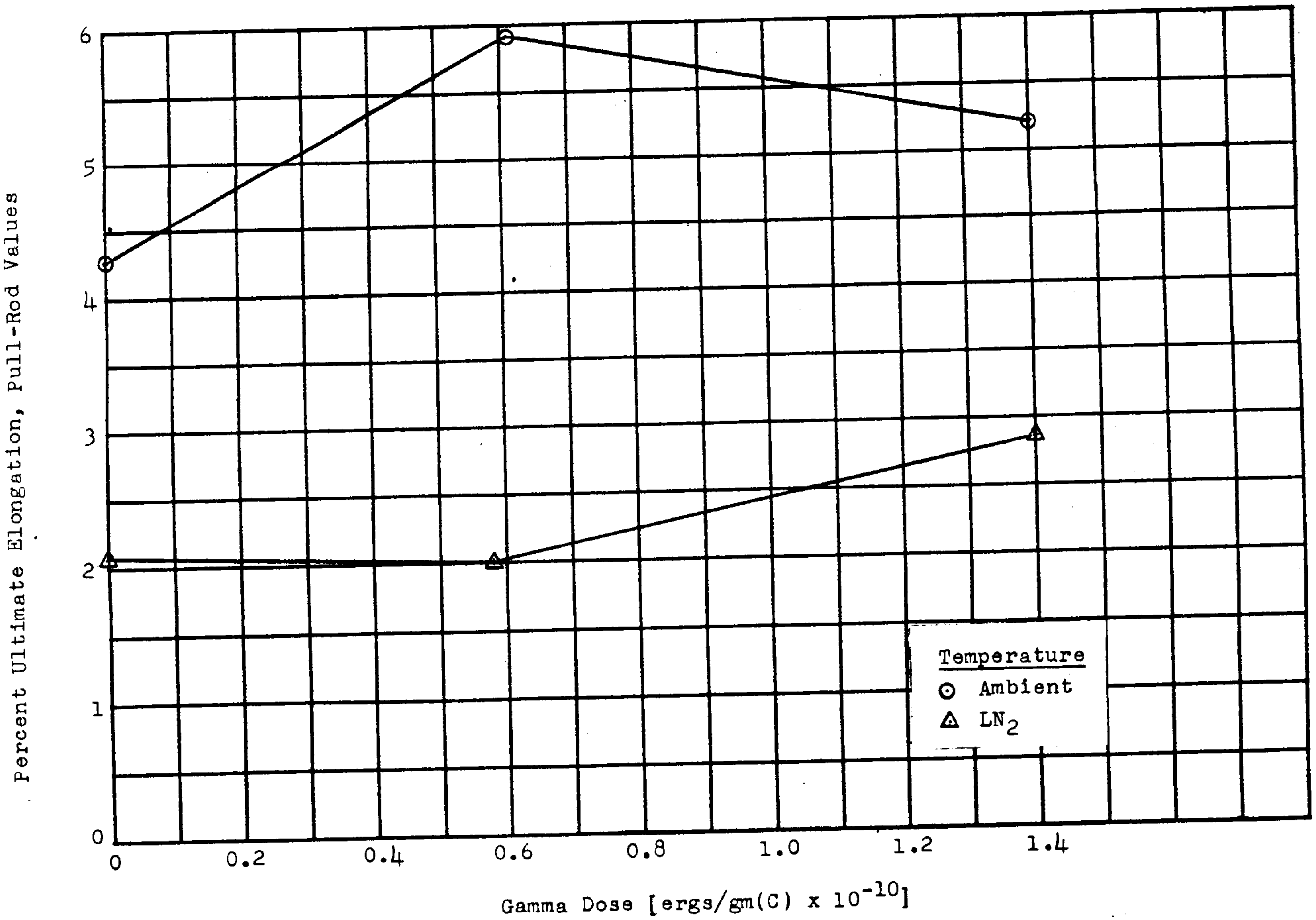


Figure 6.10 Percent Ultimate Elongation (PRV) vs Gamma Dose: Polymer-SP (Seal D)

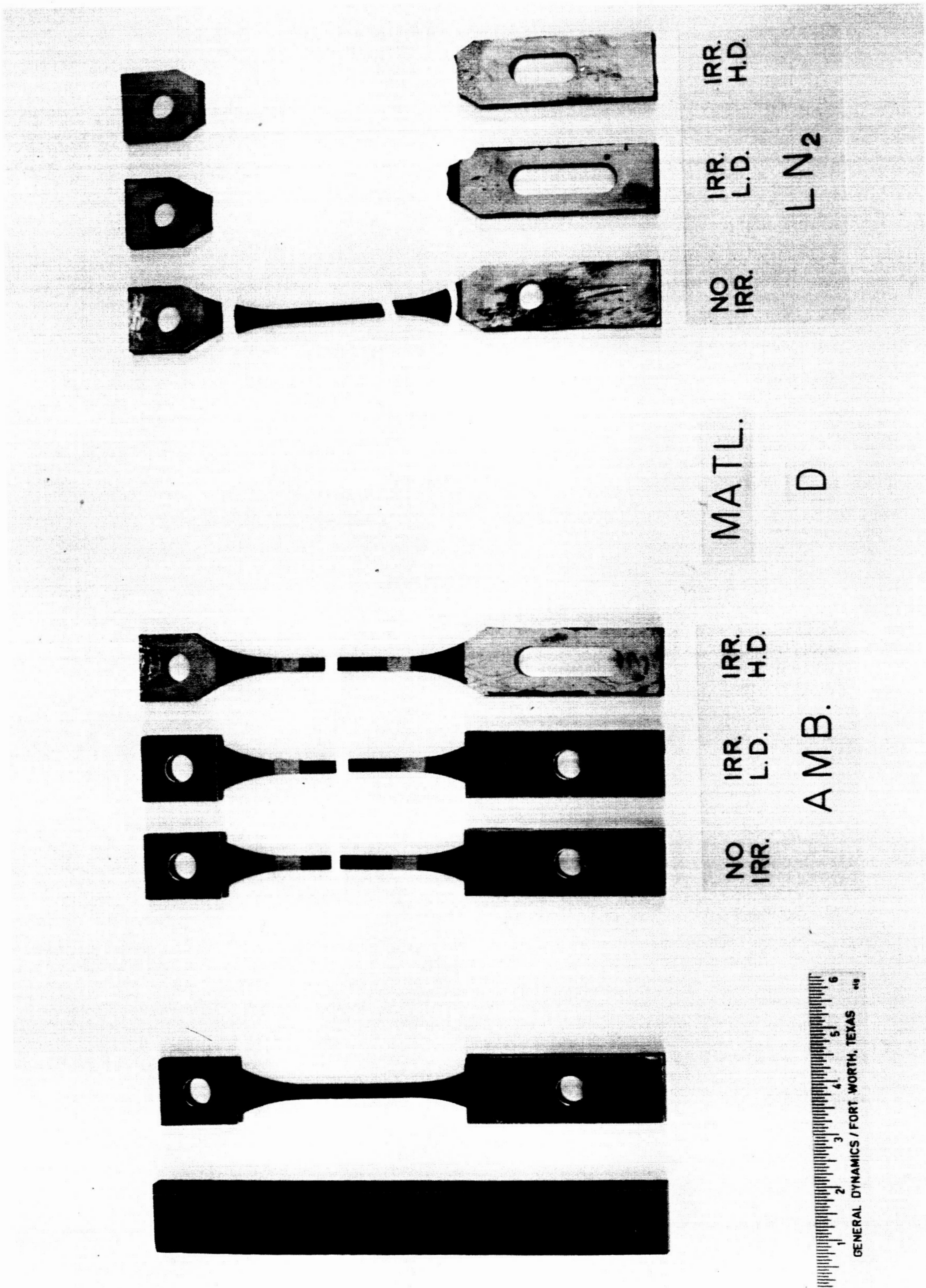


Figure 6.11 Typical Specimens of Polymer-SP (Seal D)

Specimens with the narrow gage width were tested satisfactorily in ambient-air reruns and in the LN_2 control run, while those with the wide gage width gave usable data but broke near the doublers when irradiated in LN_2. The irradiation schedules did not permit a rerun of the LN_2 irradiations, but sufficient data had been generated to demonstrate the characteristics of the material.

The ultimate tensile strength increased and total elongation decreased in the LN_2 control and irradiation runs. After irradiation in both LN_2 and air, the polyvinyl chloride plastic changed color, produced an offensive odor, and retained a high degree of radioactivity for several months. Geon 8800 is not recommended for cryogenic service in a radiation field. The data are plotted in Figures 6.12 and 6.13. Figure 6.14 is a photograph of Geon 8800 specimens.

Material I: Duroid 5600 (tetrafluoroethylene-fiberglass)

These dumbbell-type specimens pulled satisfactorily in the ambient-air control run, and stress-strain, total elongation, and ultimate tensile strength measurements were obtained. The breaks occurred in the narrow section and were classified as either "A" or "B" (see Fig. B-1). During the first ambient-air irradiation, however, the specimens became very brittle and difficult to position in the Instron without breaking. All the first-run, ambient-air, high-dose specimens were so brittle that they were broken in being removed from the test rack and, even with extreme caution on the rerun, one specimen broke before the test on the Instron.

The low ultimate tensile strength value for the April LN_2 control run has been rejected. The pull speed was variable on the

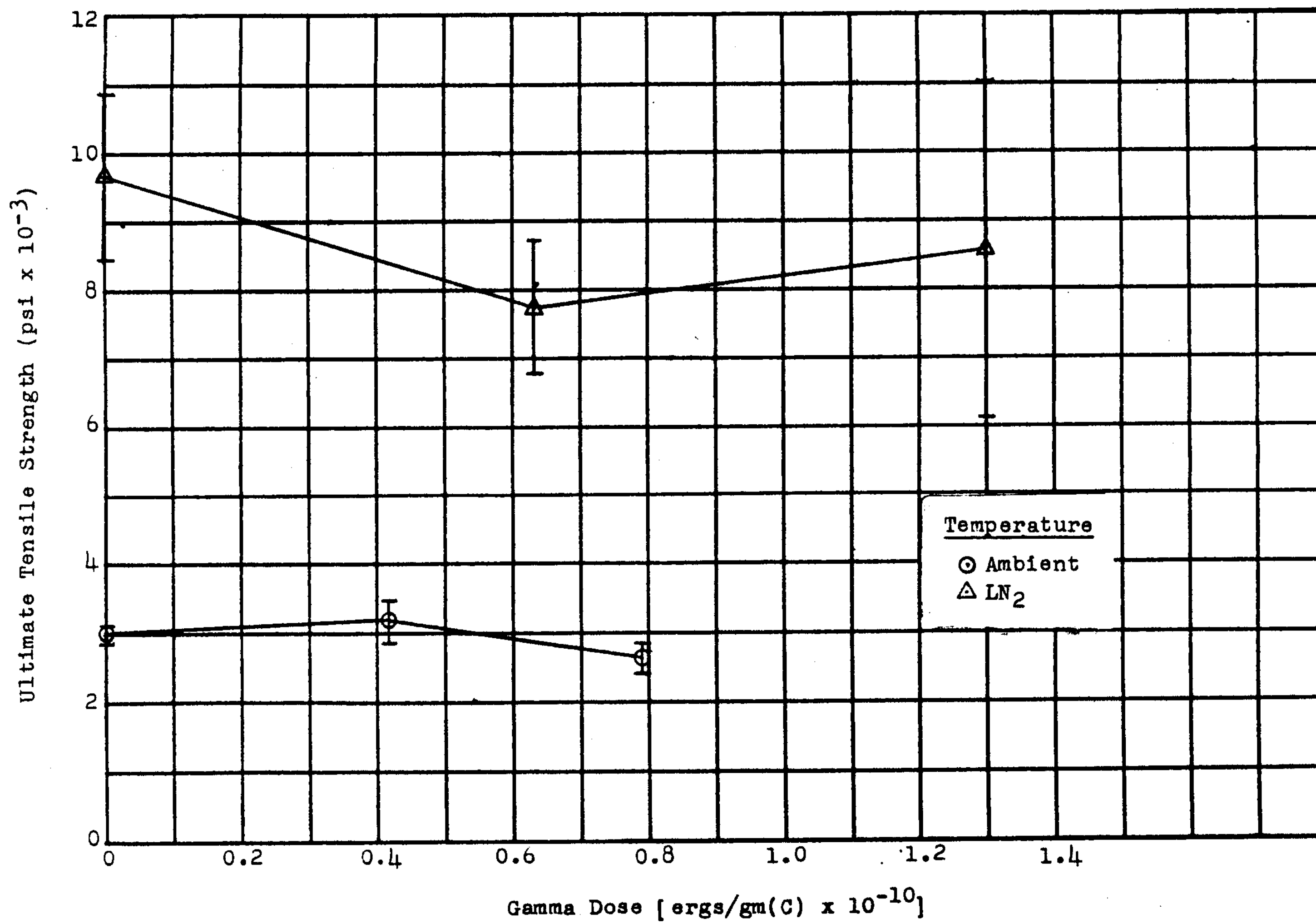


Figure 6.12 Ultimate Tensile Strength vs Gamma Dose: Geon 8800 (Electrical Insulation H)

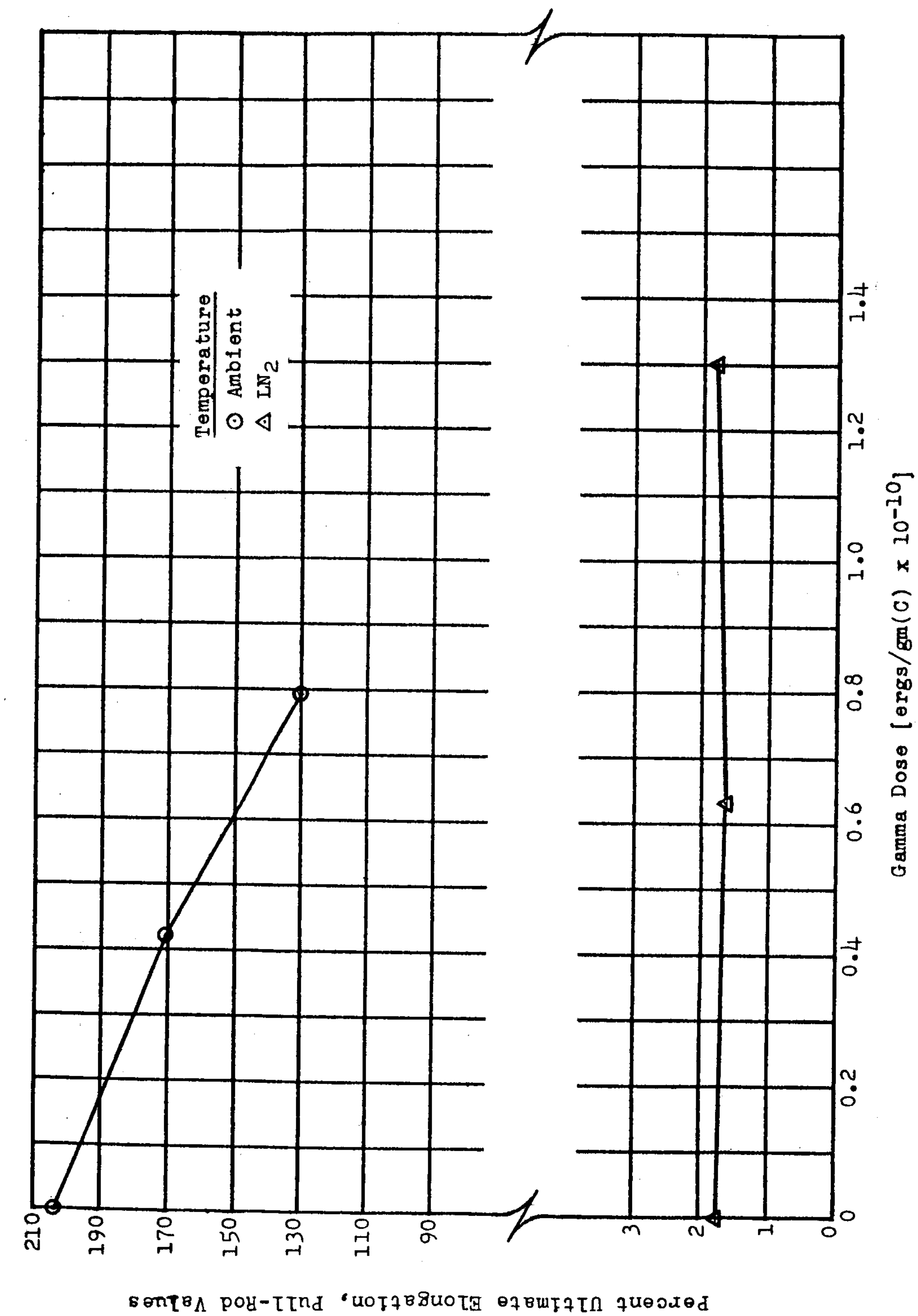


Figure 6.13 Percent Ultimate Elongation (PRV) vs Gamma Dose: Geon 8800 (Electrical Insulation H)

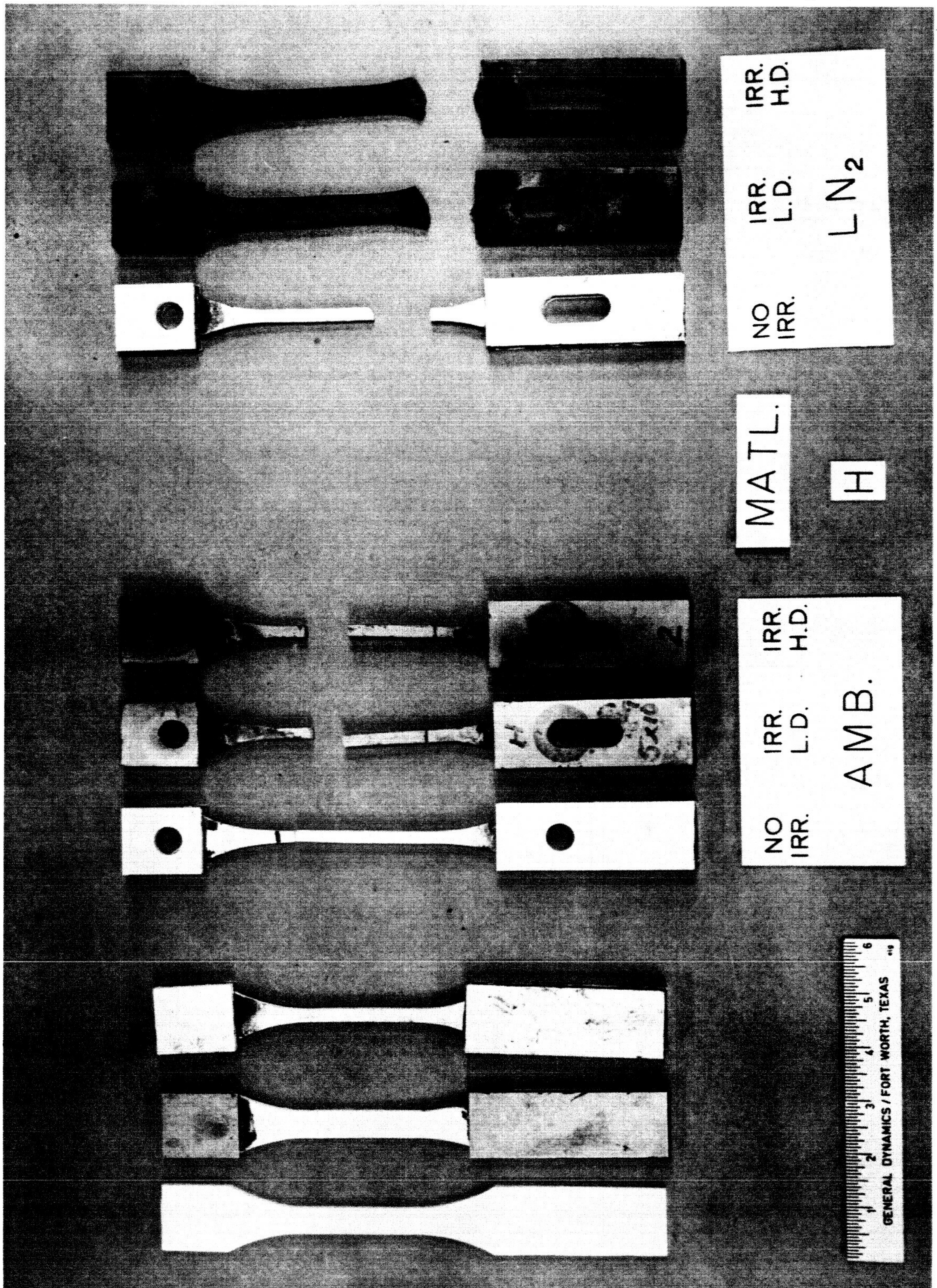


Figure 6.14 Typical Specimens of Geon 8800 (Electrical Insulation H)

first specimen; the second and third specimens were pulled at a slow rate. The August control run produced data that are more uniform and representative of the typical values for TFE in cryogenic fluids. The LN_2 irradiation run also produced better results. The Duroid 5600 material is more radiation-resistant in the cryogenic environment, as is expected of a typical TFE material. The material is not radiation-resistant in air. The data are plotted in Figures 6.15 and 6.16. Figure 6.17 is a photograph of Duroid specimens.

6.4 Laminates

Material J: Lamicoid 6038E (melamine-fiberglass)

The test results reported here are given special emphasis for three reasons. First, this material showed excellent radiation resistance at both ambient-air and LN_2 temperatures, with the tensile strength of the irradiated specimens varying very little from that of the unirradiated controls. Second, the ultimate tensile strength and total elongation at LN_2 temperature was practically double that of room temperature specimens. Third, the material had an unusual form of delamination when pulled in LN_2.

The maximum tensile strength listed for this Lamicoid by the manufacturer is 37,000 psi. This is high for a plastic material when compared to two other high-strength laminates tested in this program - CTL-91LD (phenolic) and DC-2104 (silicone), with ultimate tensile strengths of 29,300 and 16,000 psi, respectively. The ultimate tensile strength of the Lamicoid when tested at NARF was 56,500 psi for the ambient control specimens and 106,000 psi for the LN_2 control specimens.

The specimens all had excellent "A" breaks when pulled in either ambient air or LN_2; yet, in the LN_2 all specimens that were pulled,

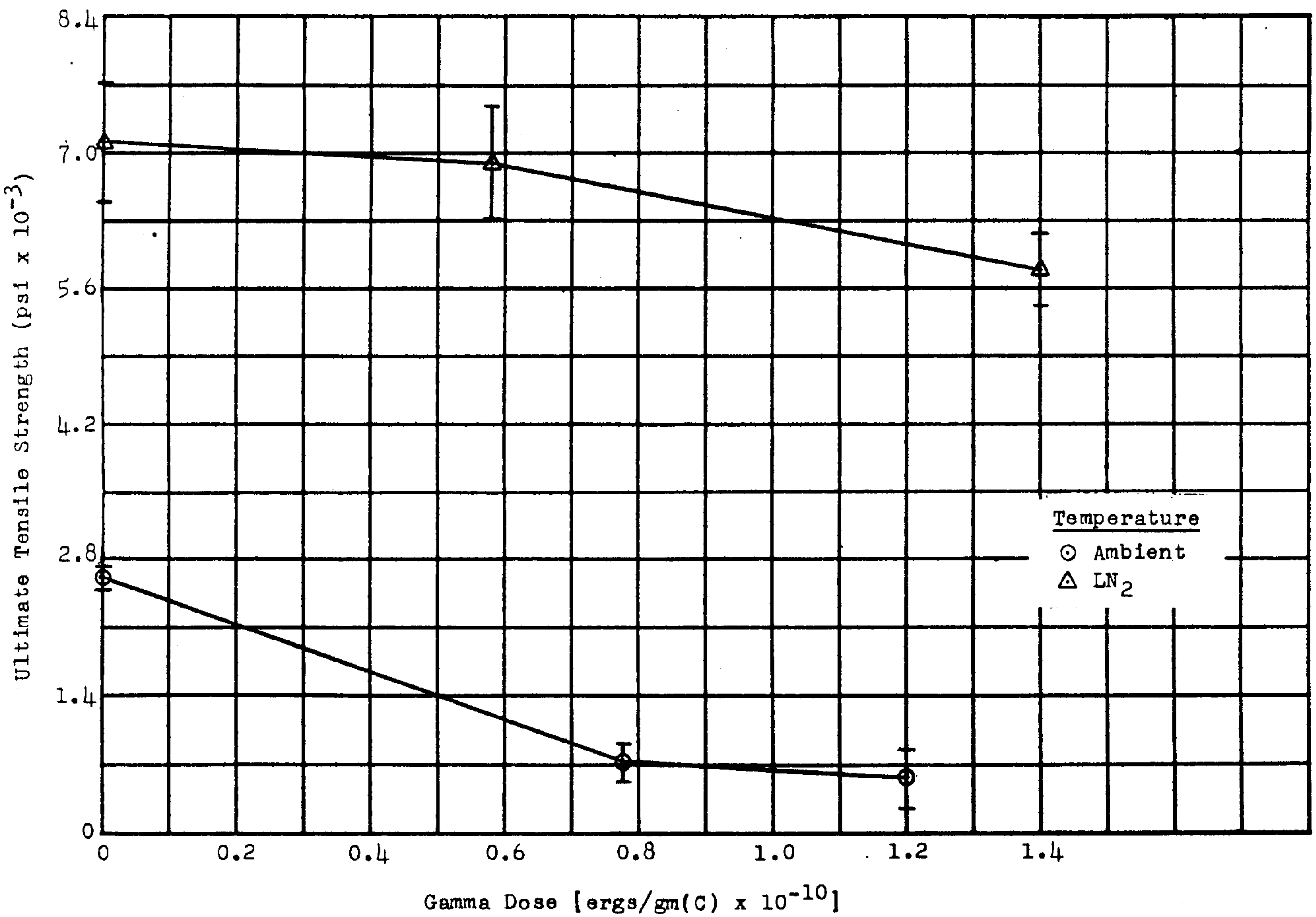


Figure 6.15 Ultimate Tensile Strength vs Gamma Dose: Duroid 5600 (Electrical Insulation I)

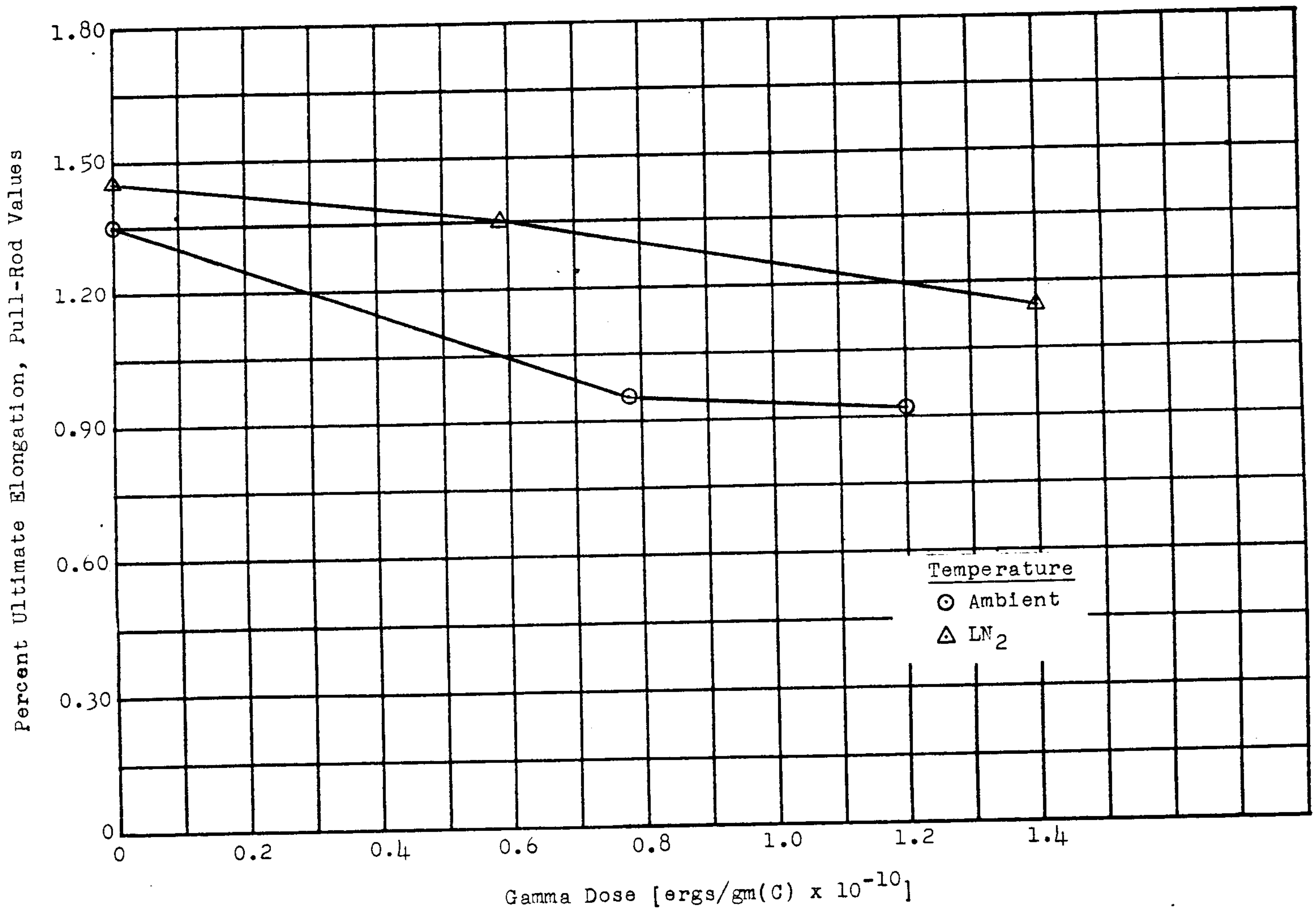


Figure 6.16 Percent Ultimate Elongation (PRV) vs Gamma Dose: Duroid 5600 (Electrical Insulation I)

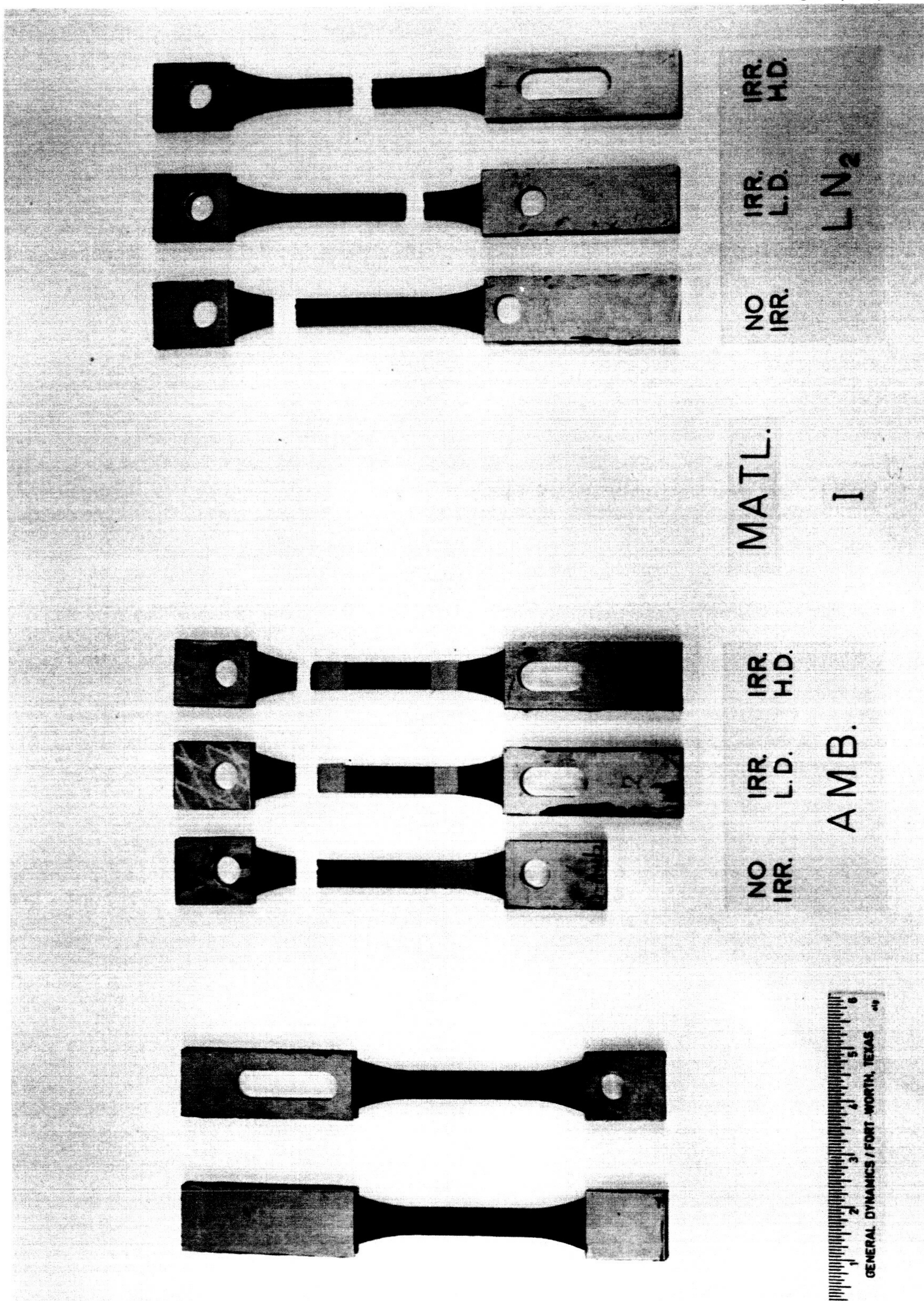


Figure 6.17 Typical Specimens of Duroid 5600 (Electrical Insulation I)

including controls, delaminated at the break-point. The individual plies all delaminated into a unique "fan" spread for the entire length of the narrow gage section, but not beyond. It was quite a different type of separation from that of the silicone laminate, which delaminated throughout its entire length, including the doubler sections. The Lamicoid specimens showed no sign of any separation in either Section C or the doubler Section D (Figure B-1). The separate fiberglass cloth plies broke at the same cross-section location.

These delaminations seem to be strictly a result of temperature effects and not a result of irradiation. Tensile properties are also virtually unaffected by radiation up to a dose of 6×10^{10} ergs/gm(C) of gamma radiation. These observations are made, however, on the limited stress-strain data presented here and further testing is suggested.

This material was developed primarily by 3M as an electrical laminate for electrical insulation applications, but in the light of its high tensile values it could be evaluated further as a structural material unless some other property restricts its structural use. Data are plotted in Figures 6.18 and 6.19. Figure 6.20 is a photograph of the specimens.

<u>Material K: CTL-91LD (phenolic-fiberglass)</u>

Tests on this material after irradiation in air revealed that it is virtually unaffected by either the low or high dose. In fact, the ultimate tensile strength increased slightly with radiation. The ultimate tensile strength of the LN_2 control specimens increased,

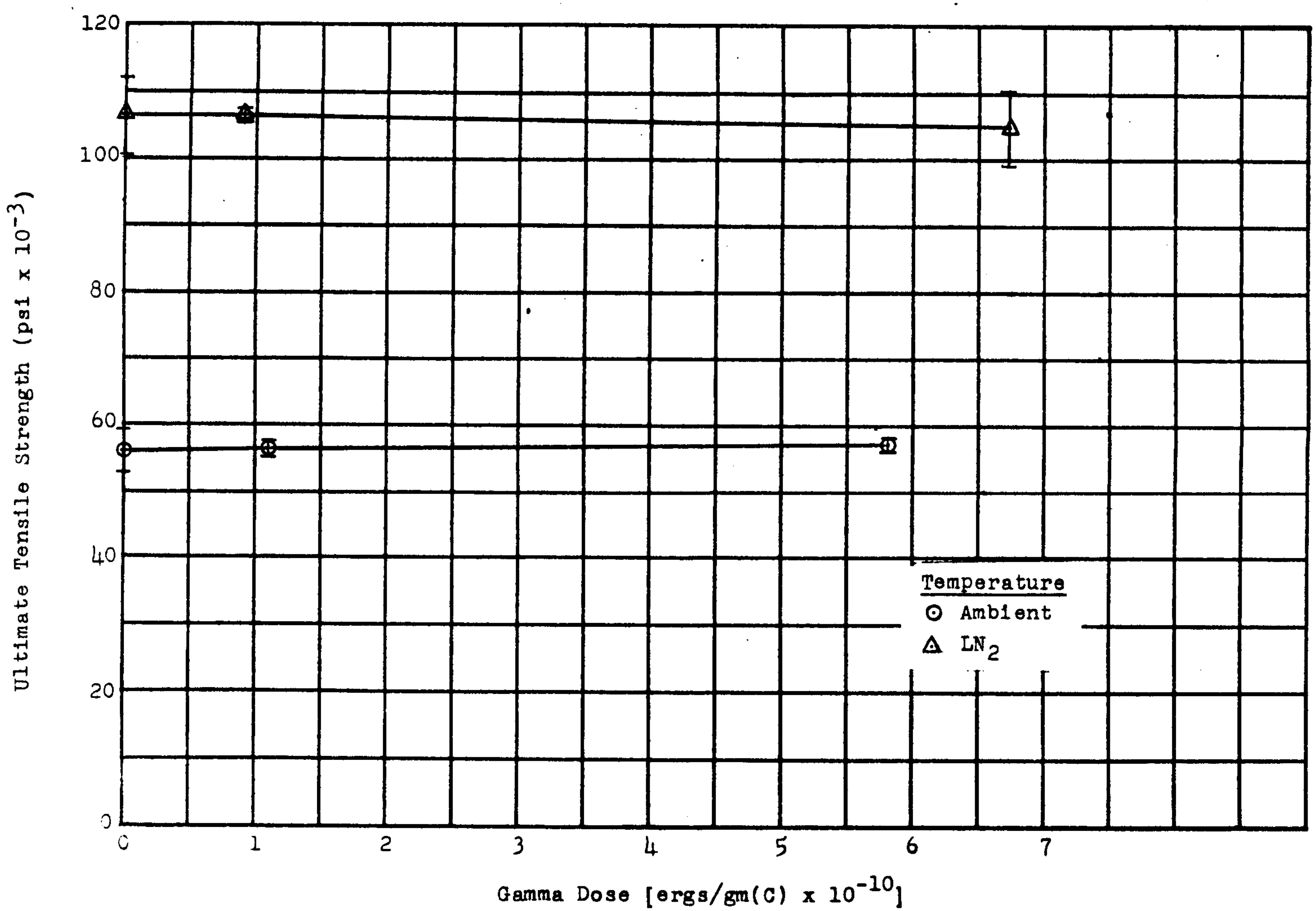


Figure 6.18 Ultimate Tensile Strength vs Gamma Dose: Lamicoid 6038E (Electrical Laminate J)

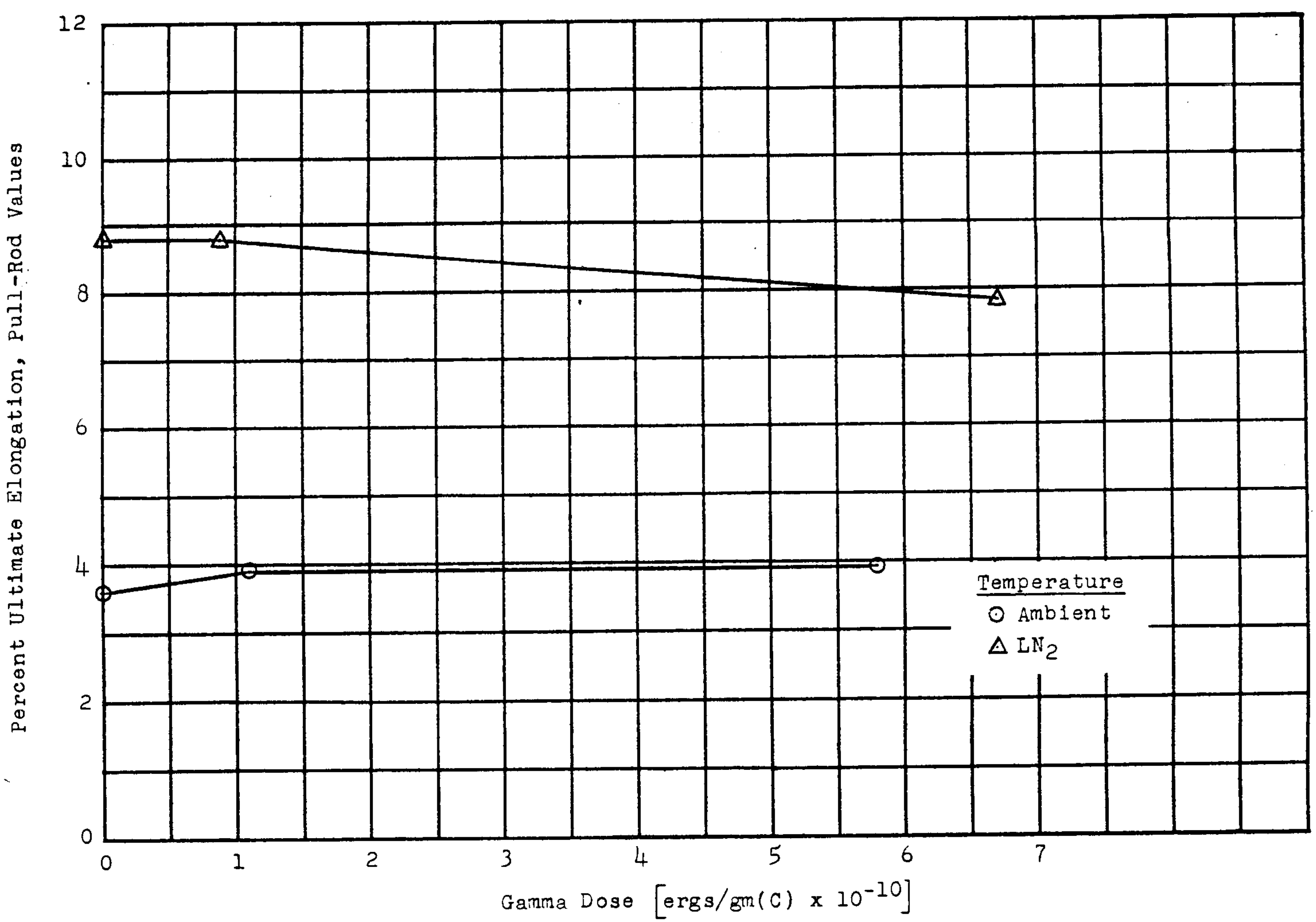


Figure 6.19 Percent Ultimate Elongation (PRV) vs Gamma Dose: Lamicoid 6038E (Electrical Laminate J)

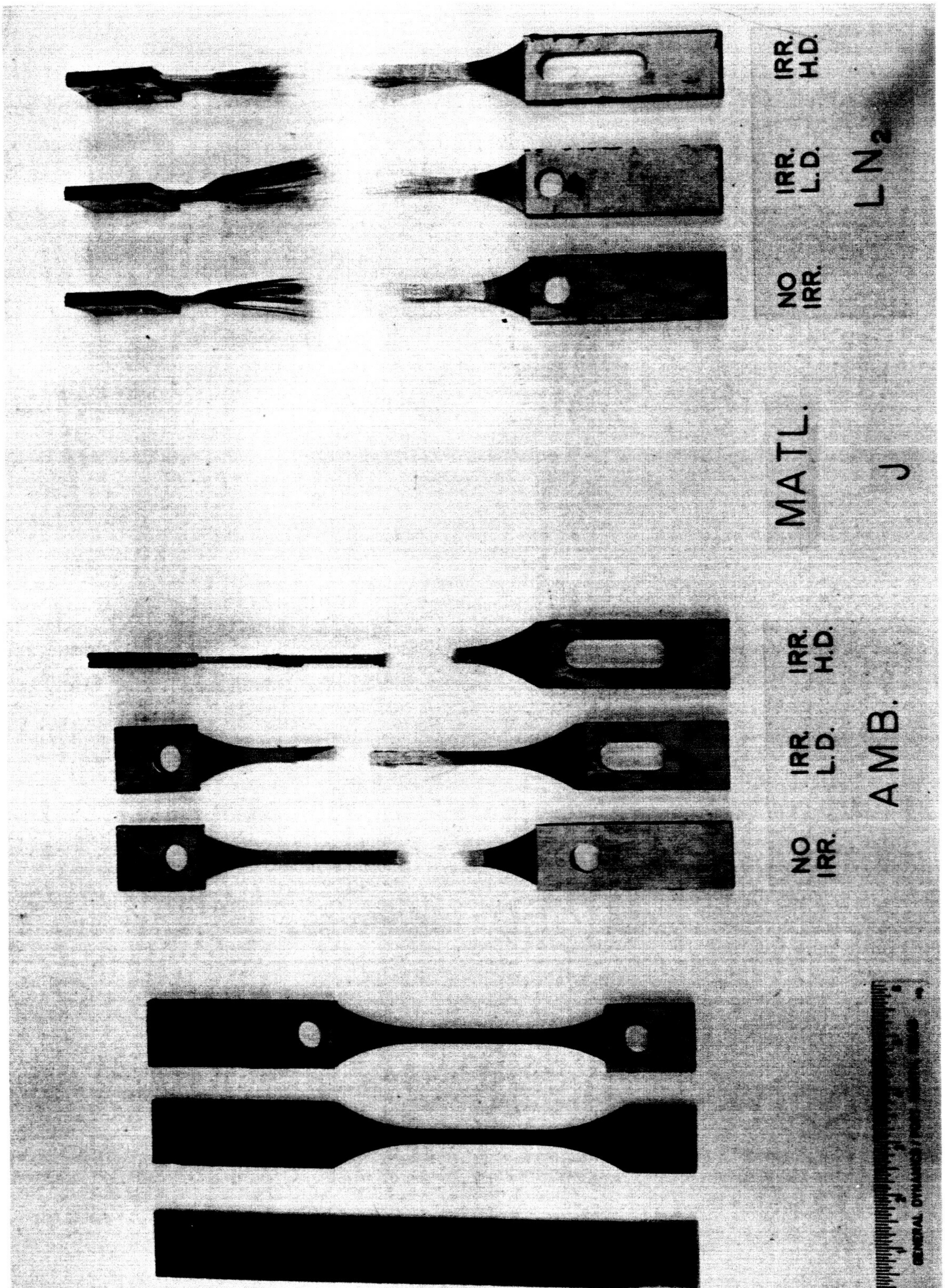


Figure 6.20 Typical Specimens of Lamicoid 6038E (Electrical Laminate J)

but after irradiation in LN_2 to the high dose, both the ultimate tensile strength and total elongation were reduced. However, the final tensile value after the high dose in LN_2 was still above that of the ambient controls.

The narrow 1/4-in. gage specimens all produced good "B" breaks with no delamination or shredding of the fiberglass when broken in LN_2, as was experienced by the other laminates. The data are plotted in Figures 6.21 and 6.22. Figure 6.23 is a photograph of the specimens.

Material L: Dow Corning 2104 (silicone-fiberglass)

This silicone laminate followed the phenolic laminate pattern of having the ultimate tensile strength and total elongation increase slightly when irradiated and tested in ambient air. When tested in LN_2, the ultimate tensile strength of control specimens tripled and the total elongation doubled. Tests after irradiation in LN_2 showed the material to be virtually unaffected by either the low or high dose of radiation. This observation is made, however, on the limited stress-strain data presented here, and further testing is suggested.

During the initial tensile tests in LN_2, the silicone specimens had random delaminations, including the ends of some under the doublers. Since delamination was between the plies of the fiberglass, it was not a failure of the Epon 934 adhesive. A solution to doubler-end delamination was effected by riveting the doublers together in addition to bonding them to the specimens. The combination of rivets and adhesive then held for subsequent LN_2

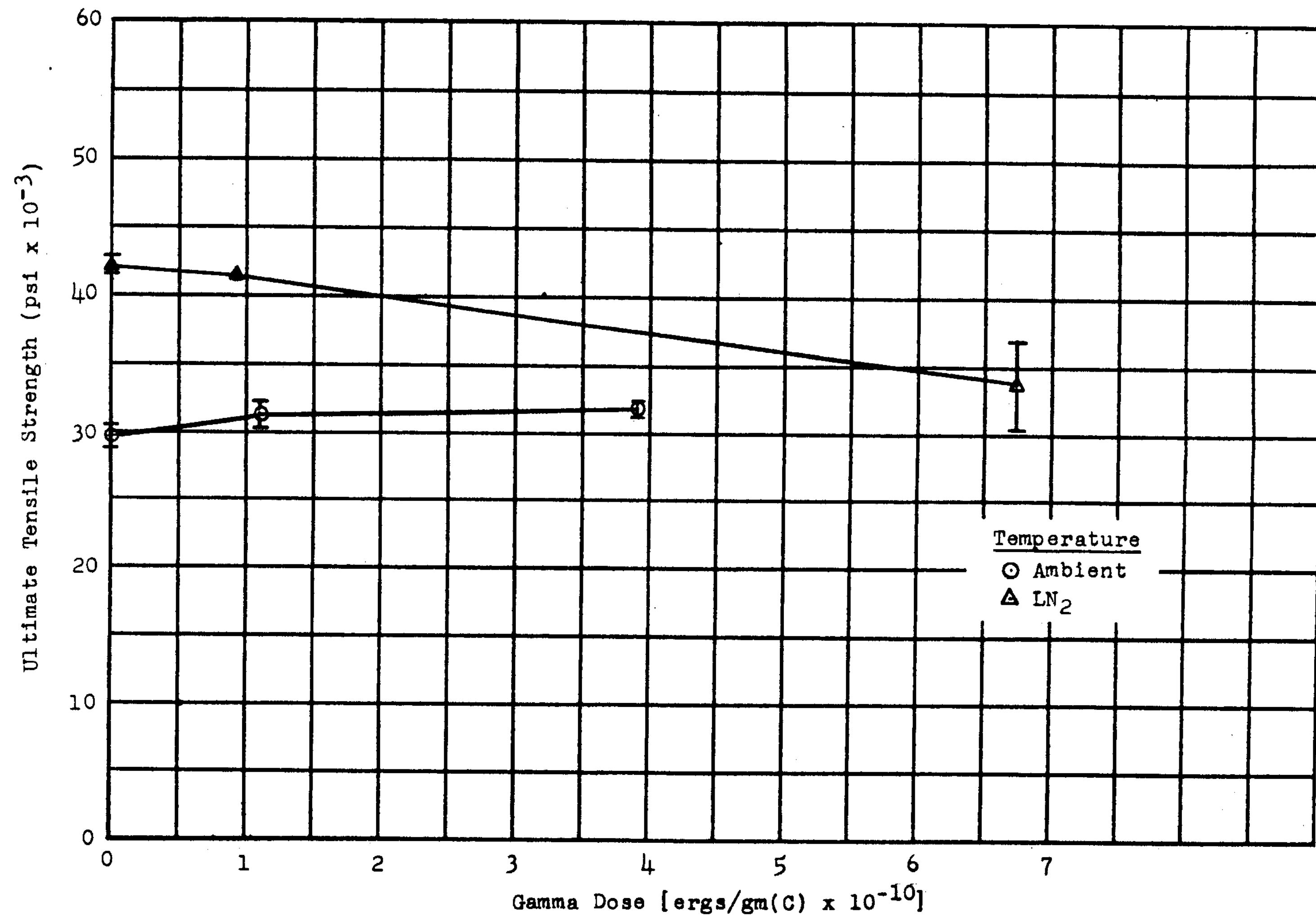


Figure 6.21 Ultimate Tensile Strength vs Gamma Dose: CTL 91LD (Structural Laminate K)

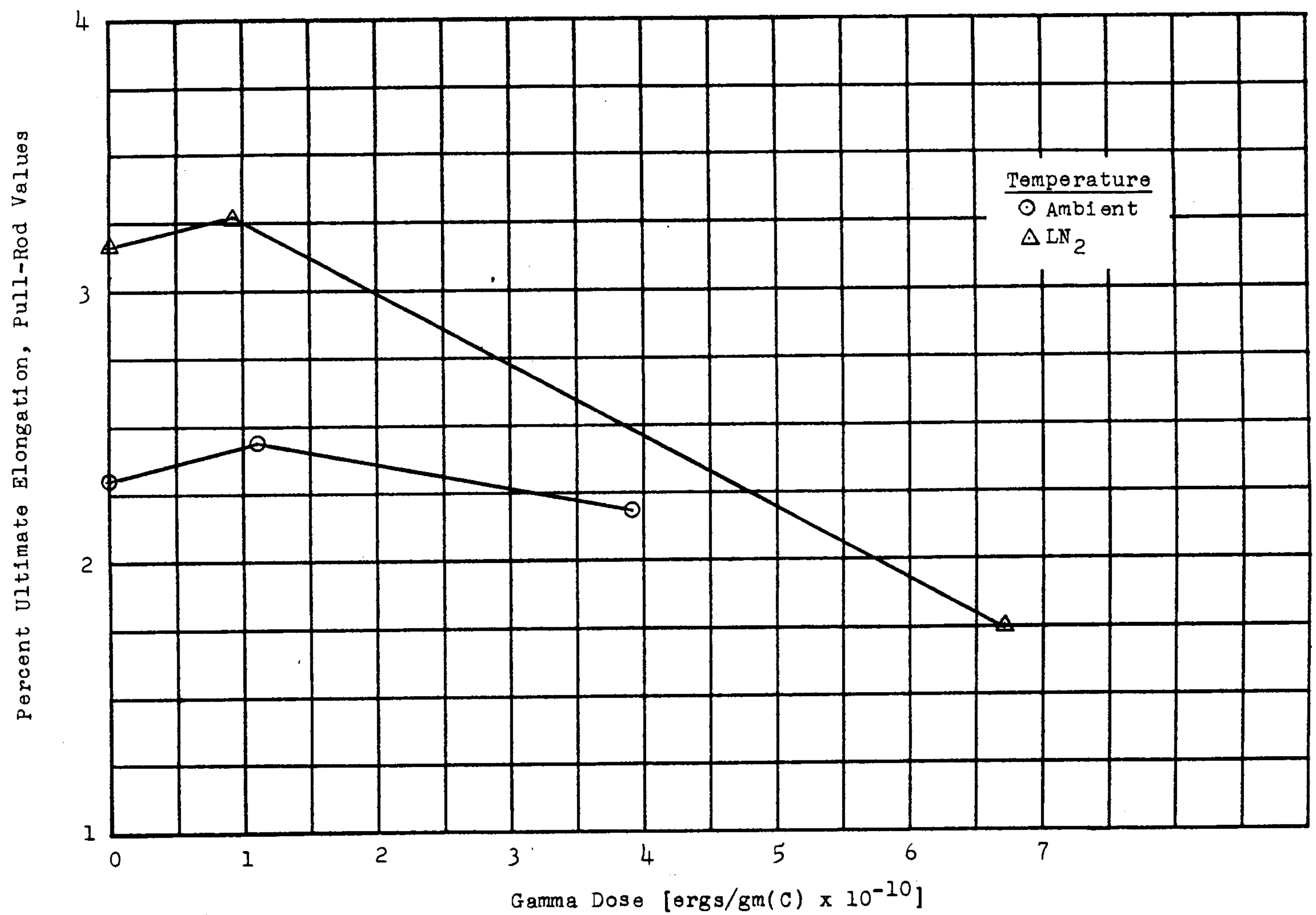
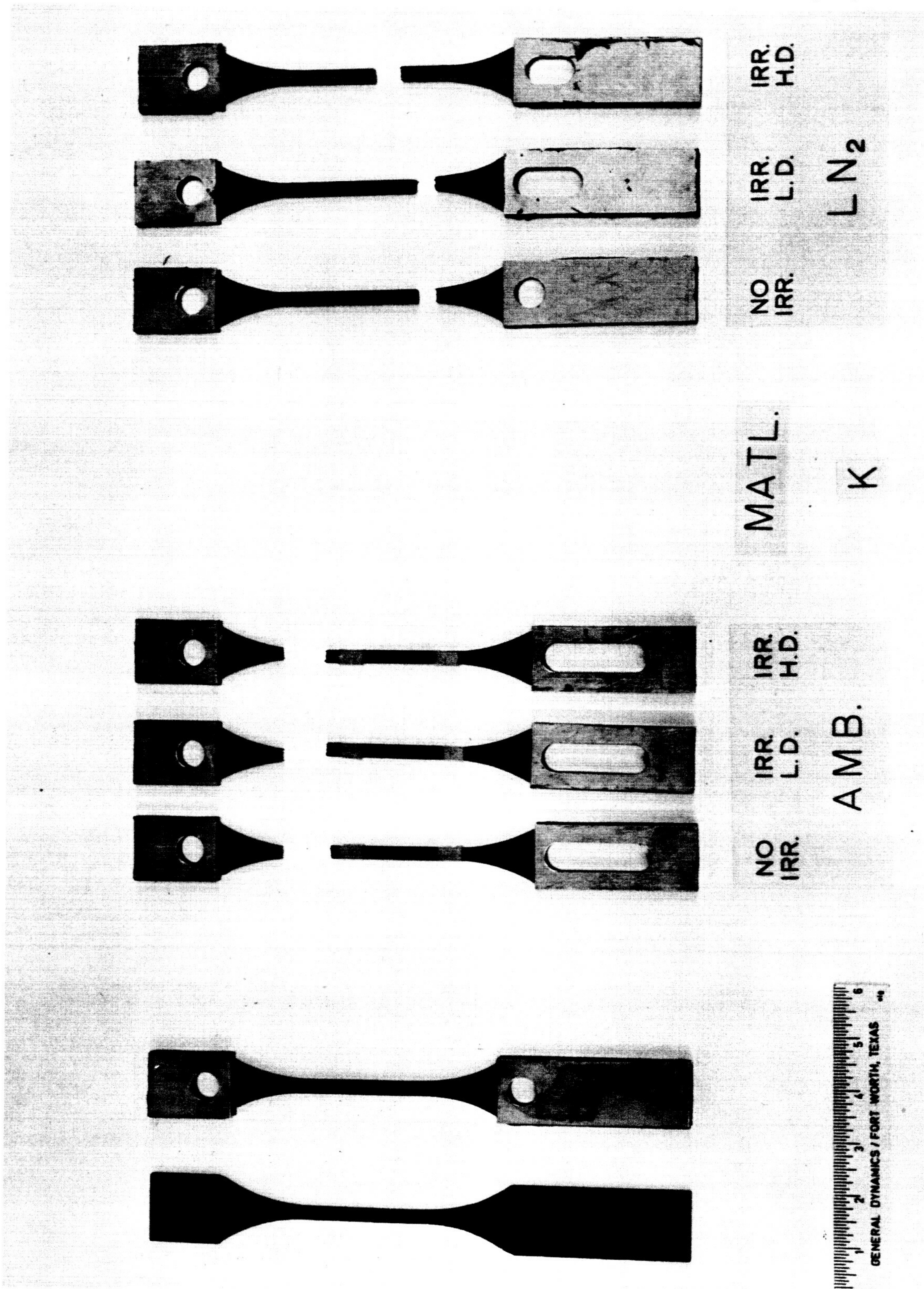


Figure 6.22 Percent Ultimate Elongation (PRV) vs Gamma Dose: CTL 91LD (Structural Laminate K)


NO IRR.
IRR. L.D.
IRR. H.D.
LN2
MATL.
K
NO IRR.
IRR. L.D.
IRR. H.D.
AMB.
GENERAL DYNAMICS / FORT WORTH, TEXAS

tests. However, the LN_2 low-dose specimens that had been riveted continued to delaminate badly at the break points in the narrow-gage-length section. The individual plies continued to break at various and random places along the narrow section with a shredding of the fiberglass starting at the separation point. It seems that the delaminations result from temperature effects and are not a result of irradiation. Data are plotted in Figures 6.24 and 6.25. Figure 6.26 is a photograph of specimens.

6.5 Dielectrics

Material Q: Teflon TFE No. 7 (tetrafluoroethylene)

When irradiation space became available during the middle of the year, Teflon was added to the test program to obtain cryogenic tensile data, since it had been irradiated in ambient air but not at cryotemperatures during the first year's program.

The tensile properties of Teflon vary with the method of fabrication, particle configuration, degree of crystallinity, and test conditions. A discussion of this variance has been covered in Section 4.4 of the vacuum portion of the second annual report (Ref. 1).

To check out the effects of different pull rates, a specimen from the lot supplied by Dore for this year's tests was pulled at 1/2 in./min in the Instron while submerged in LN_2. The ultimate tensile strength of 9880 psi agrees with the cryogenic experimental assembly average value of 10,000 psi (pulled at 1/2 in./min) within the standard deviation on an individual basis.

The irradiated LN_2 specimens demonstrated a 50% decrease in total elongation and, upon opening the dewar after the test, were

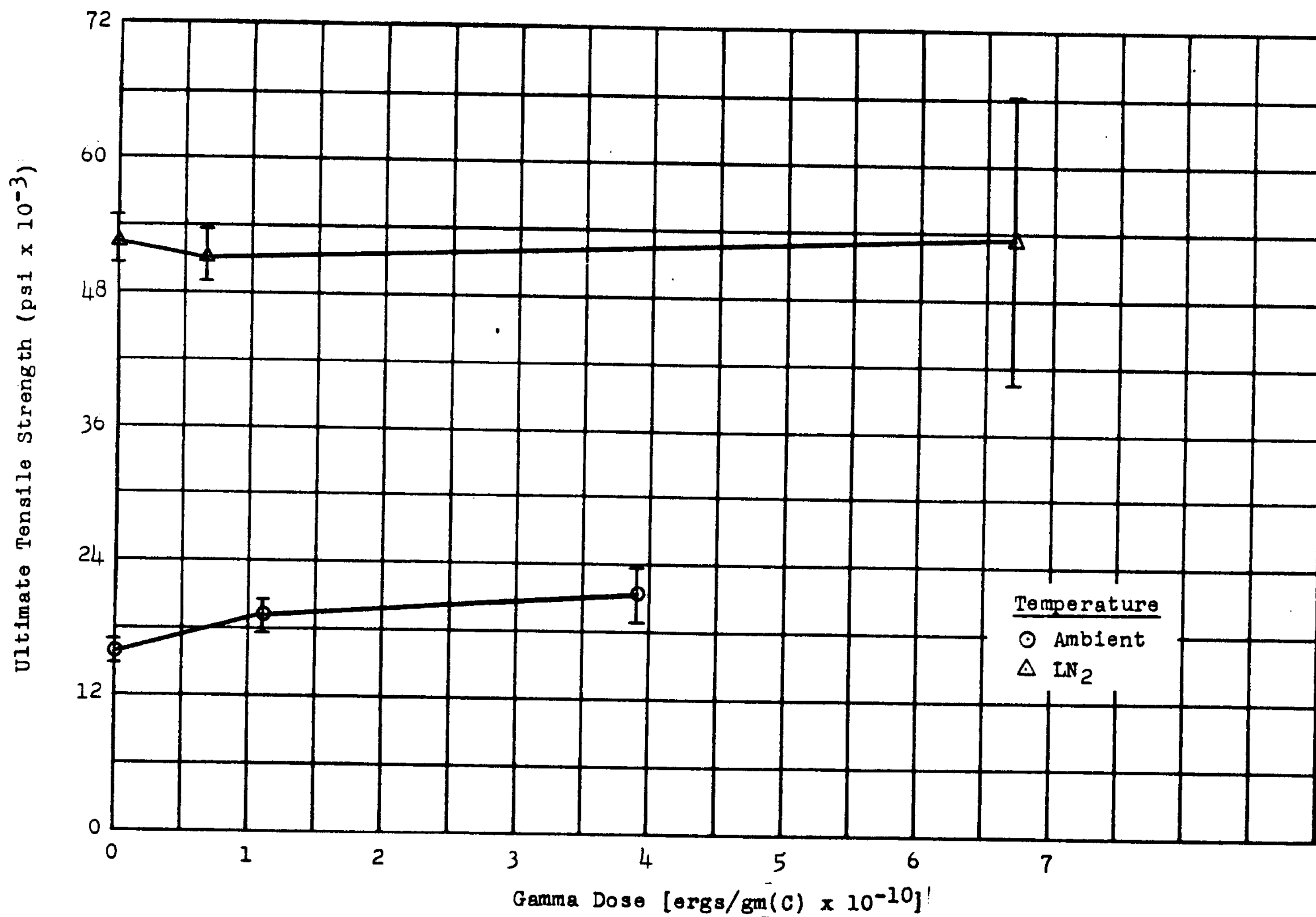


Figure 6.24 Ultimate Tensile Strength vs Gamma Dose: Dow Corning 2104 (Structural Laminate L)

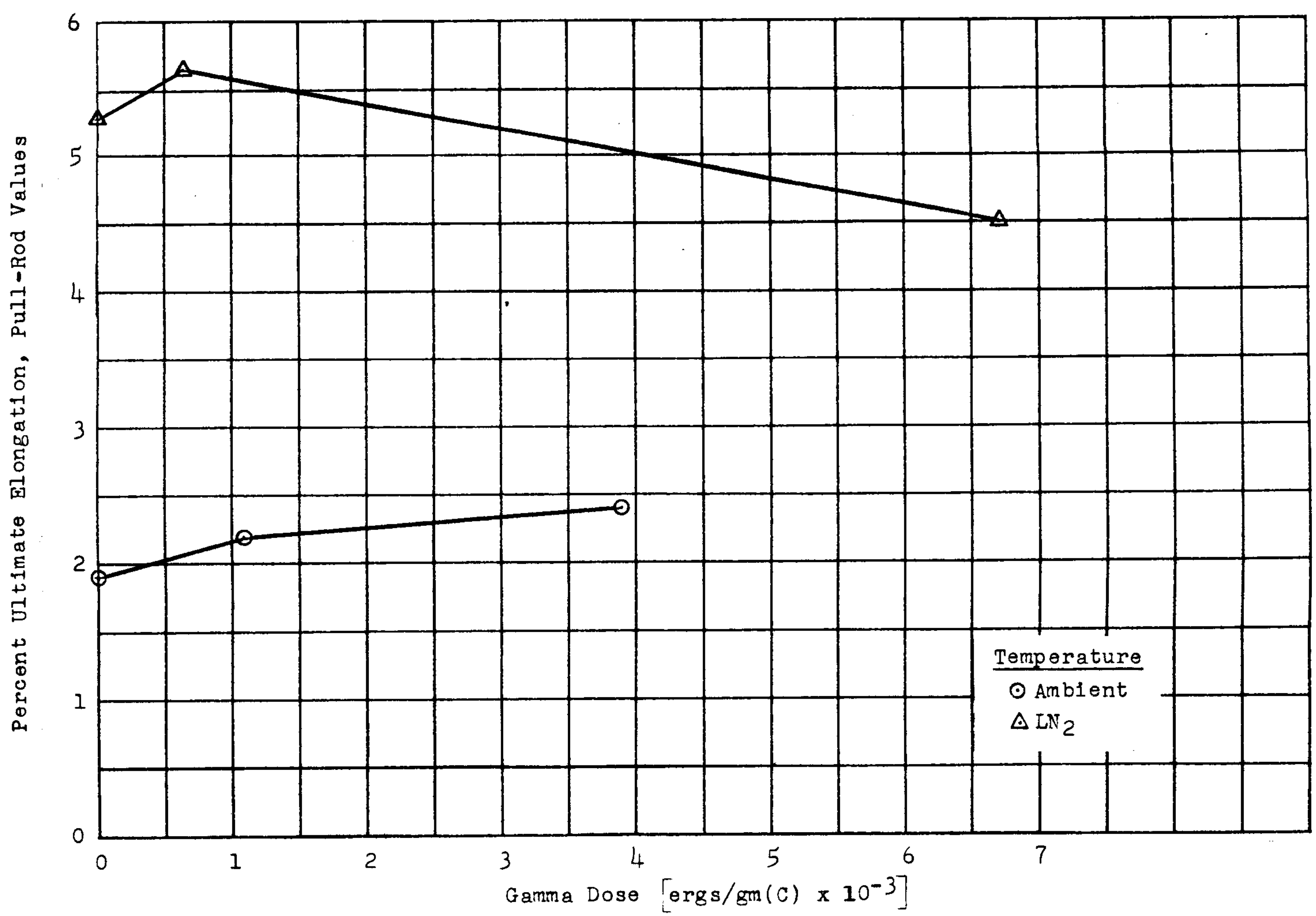


Figure 6.25 Percent Ultimate Elongation (PRV) vs Gamma Dose: Dow Corning 2104 (Structural Laminate L)

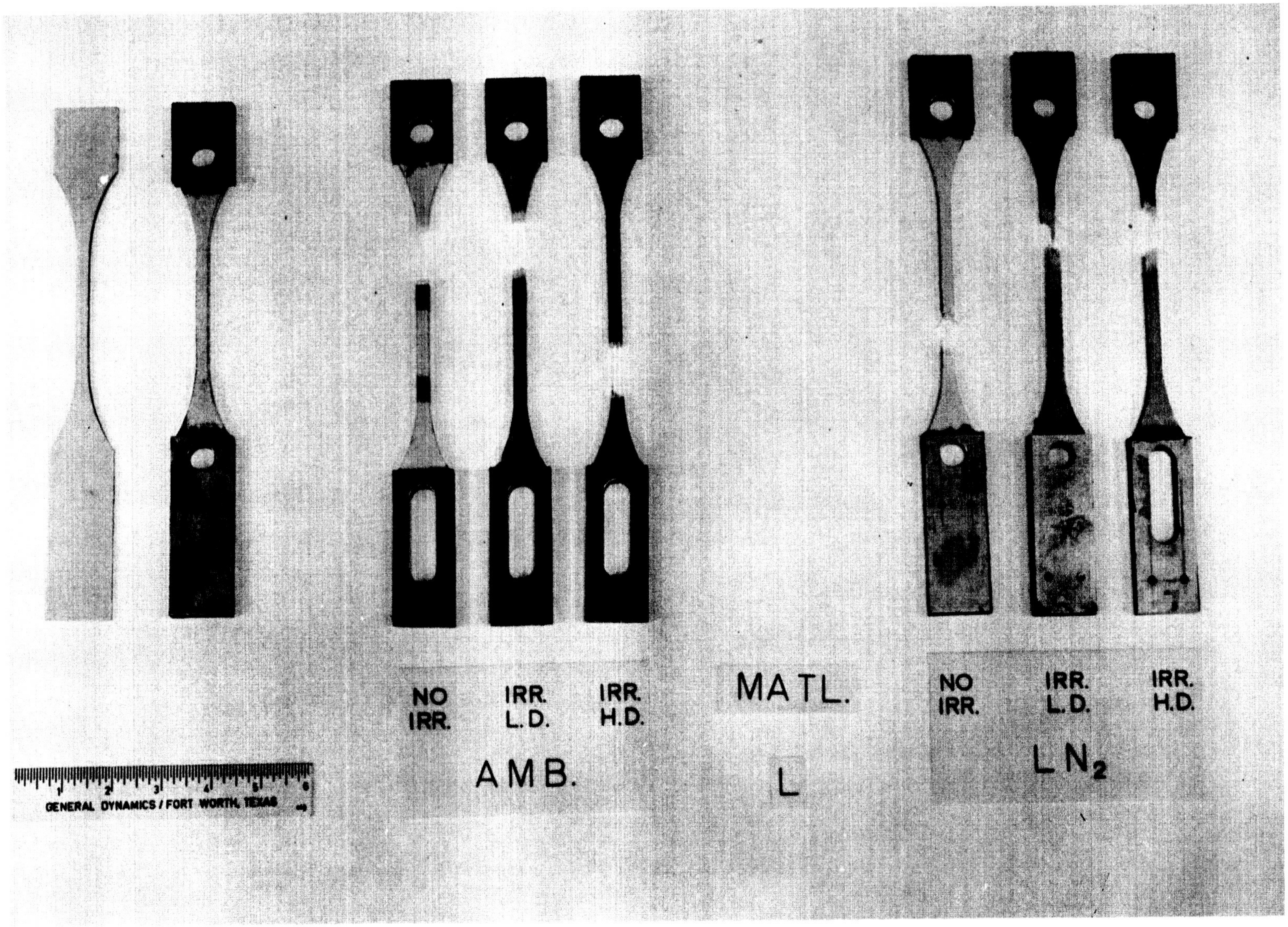


Figure 6.26 Typical Specimens of Dow Corning 2104 (Structural Laminate L)

found to be broken in several places. Teflon is brittle after irradiation at LN_2 temperature, but it was assumed that the initial break during the postirradiation tensile test in the cryogenic experimental assembly at the temperature of LN_2 had taken place in the narrow section, similar to the breaks obtained with the control specimens.

Ultimate tensile strength decreased a little with radiation, but retained its strength much better in liquid nitrogen that in air at the same radiation level. The data are plotted in Figures 6.27 and 6.28. Figure 6.29 is a photograph of the specimens.

6.6 Potting Compounds

Material M: Epon 828/Z (epoxy)

The pull-out strength of the potted wires ranged from 35 to 39 lb for both the ambient and LN_2 controls and ambient-air low and high dose. On the other hand, 64 lb of pull were required for the LN_2 low dose, with no known reason for this high value other than a possible error in calculation of the tare load. The pull-out load was only 19 lb for the LN_2 high dose.

Visual inspection with a 6X magnifying glass indicated that all wires pulled out of the epoxy compound except for wire No. 4 in the LN_2 low-dose test. The wire broke above the compound, without any visible signs of cracks around the base of the wire. The wires were all coated with a brown material on the ends after the pulls. Furthermore, in cases where the wires did not pull out, but broke, the pull strength was around 38 lb for both this material and the potting compound, EC-2273B/A (in this section and in tests under the vacuum section). Since the wires broke at 38 lb, it is

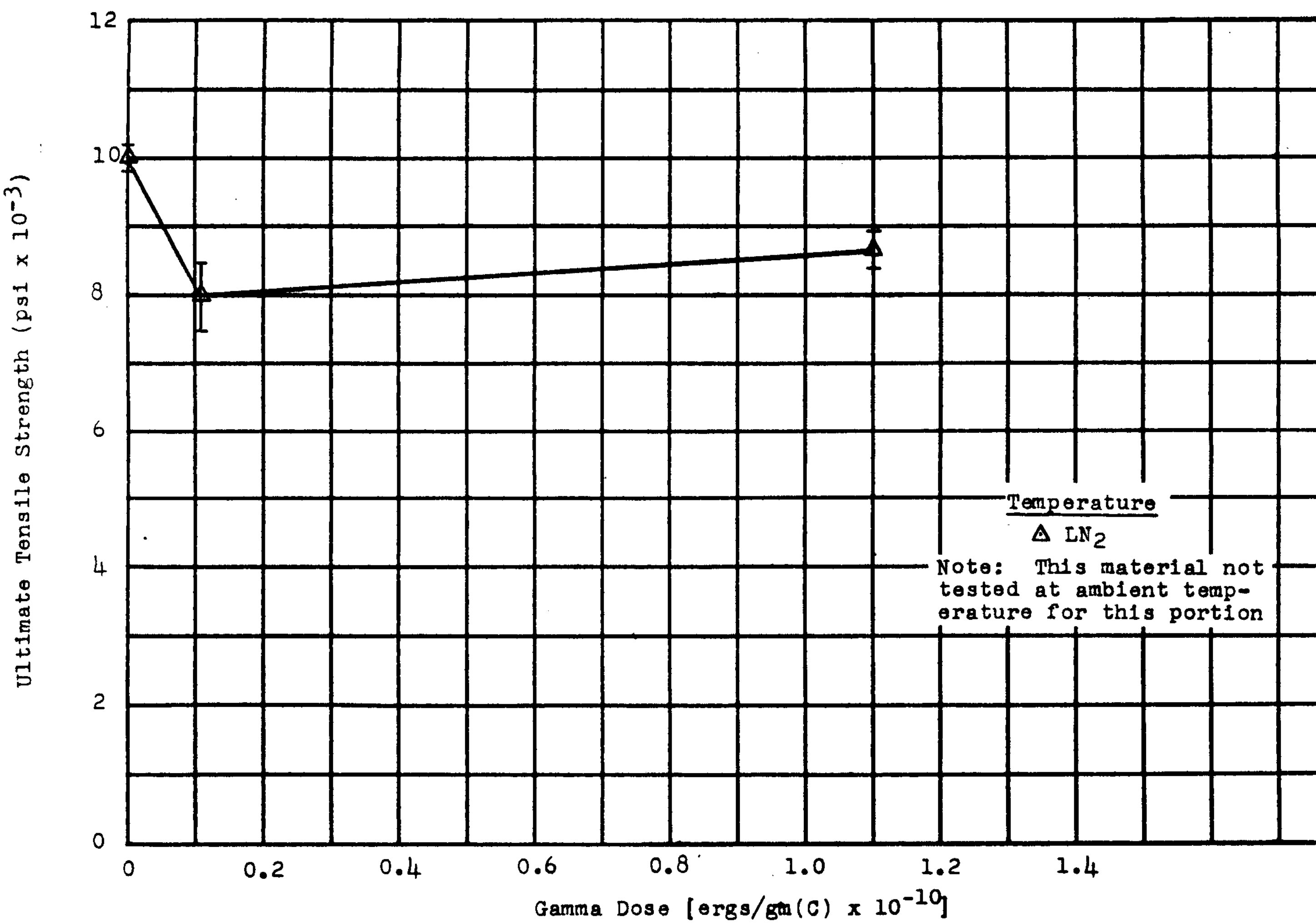


Figure 6.27 Ultimate Tensile Strength vs Gamma Dose: Teflon TFE-7 (Dielectric Q)

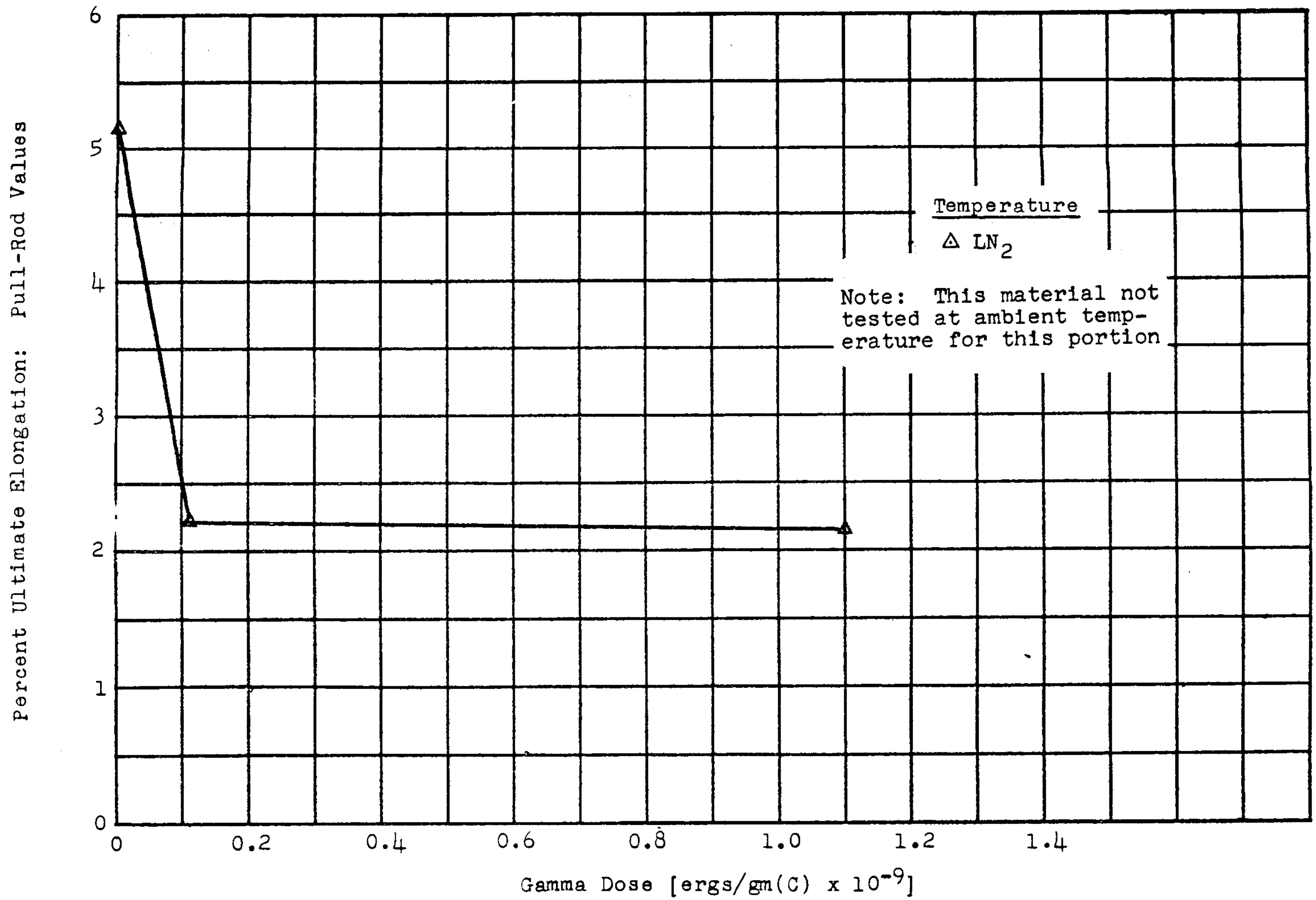


Figure 6.28 Percent Ultimate Elongation (PRV) vs Gamma Dose: Teflon TFE-7 (Dielectric Q)

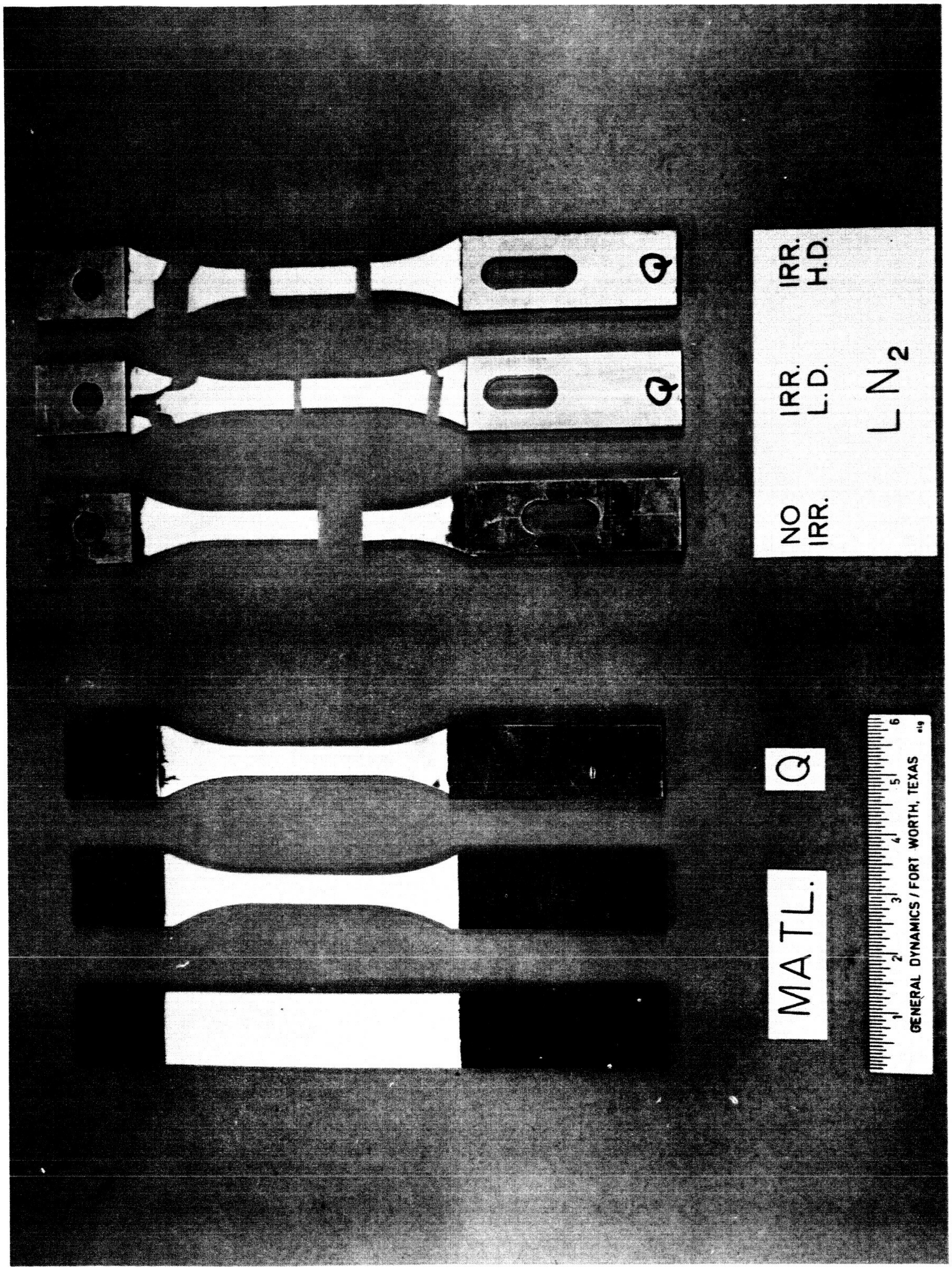


Figure 6.29 Typical Specimens of Teflon TFE-7 (Dielectric Q)

assumed that the recorded 64 lb is not a true value but represented a high tare load that was not deducted.

Based on the test data and visual observations, it may be concluded that there was little degradation of the Epon 828/Z except at the LN_2 high dose. The adhesive Aerobond 422J (material B) had almost the same load pattern with very little degradation except at the high dose in LN_2. In addition, the Epon 934 adhesive, used in bonding the doublers on the tensile dumbbell specimens, gave excellent service in the ambient and LN_2 irradiations. This epoxy potting compound should be considered in any carry-on test program. Data are plotted in Figure 6.30 and Figure 6.31 is a photograph of typical potting compound, adhesive, and T-peel specimens.

Material N: EC-2273B/A (chemical composition proprietary)

The ambient-air potted-wire control specimens broke just above the mold at a 38-lb pull. Since the established wire strength is 38 lb, the failure was in the wire. The compound adhesive strength was not determined, except that it was higher than 38 lb.

In the ambient-air low- and high-dose runs, the wires pulled out. In specimen preparation, the wire ends and interior of the mold were primed before potting with a light-green primer (chemical name and composition proprietary). After the pulls, all wire ends were still coated with green primer. This indicates that on pulling, adhesive failure took place between the primer and the EC-2273B/A.

Trouble occurred in the LN_2 tests when the molded compound separated from the metal holder. The potting compound in the control and high-dose runs pulled completely out of the holder, and the low-

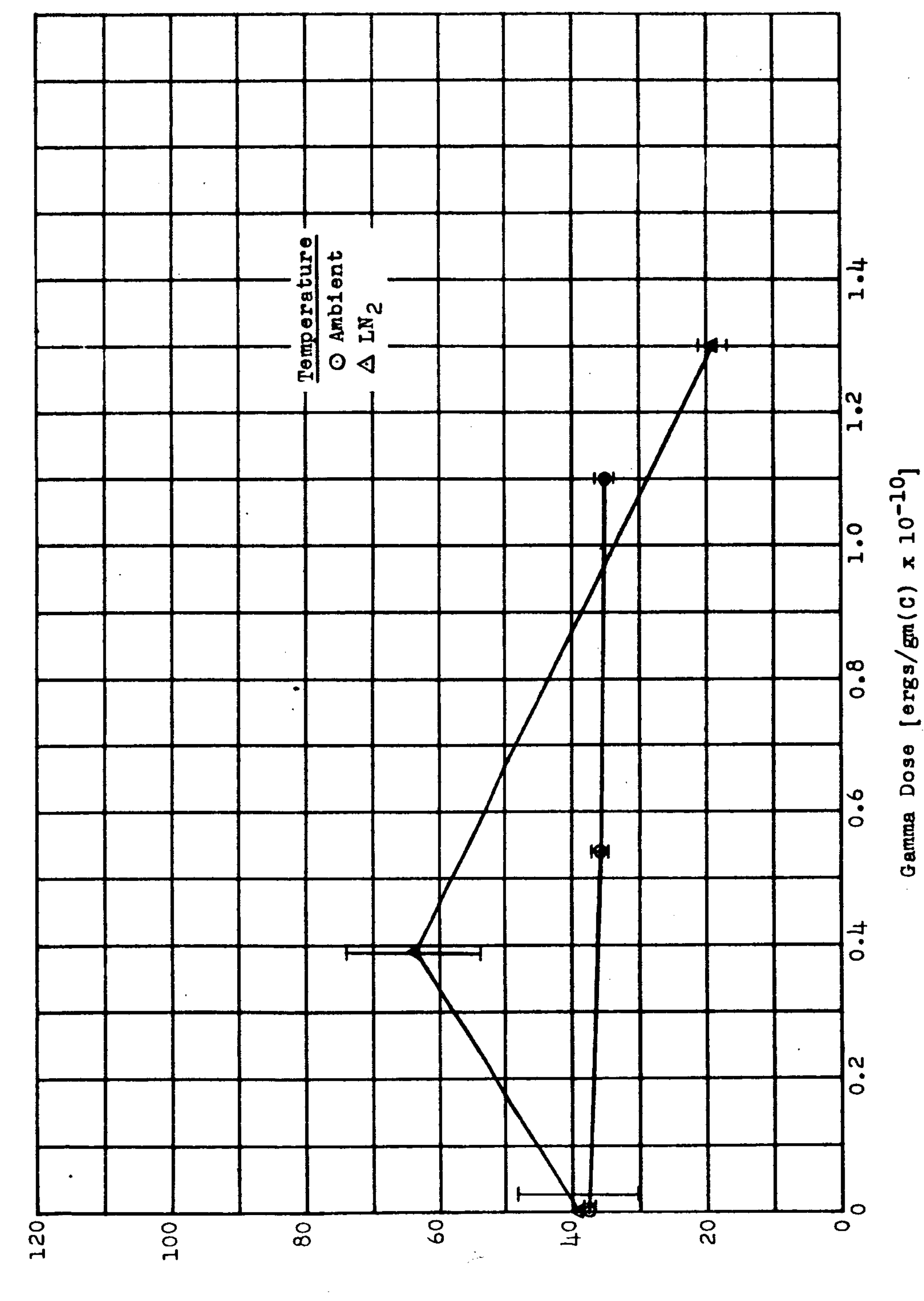


Figure 6.30 Potted-Wire Pull-Out Load vs Gamma Dose: Epon 828/Z (Potting Compound M)

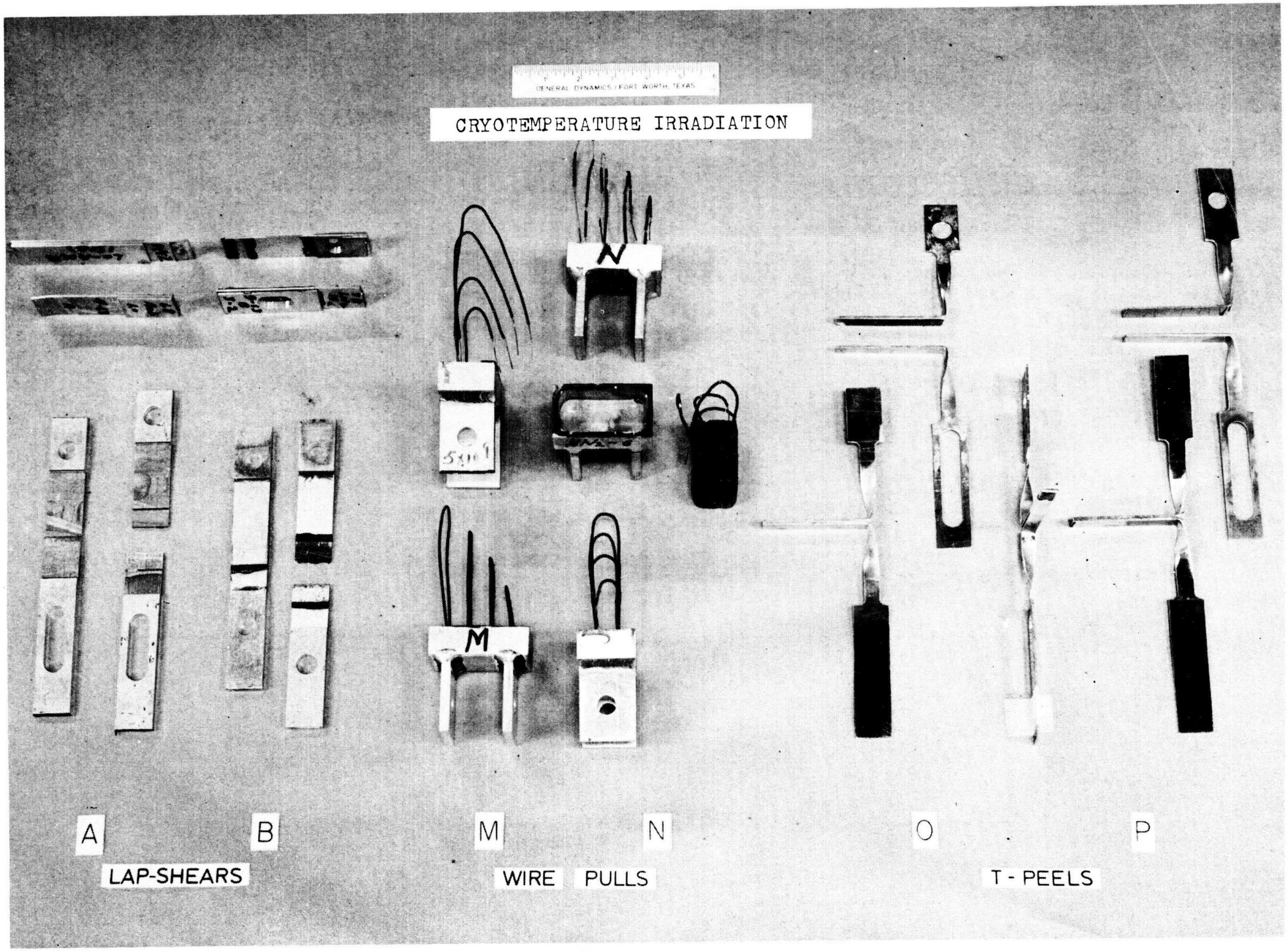


Figure 6.31 Typical Specimens of Scotchweld AF-40 and Aerobond 422-J (Adhesive A & B), Epon 828/Z and EC-2273B/A (Potting Compounds M & N), and EC-1949 and EC-1663 (Sealants O & P)

dose potting compound was loose in the holder after testing. After removal from the holder, the black EC-2273B/A potting compound was still completely coated with the primer; hence failure had to be between the primer and metal holder. Also, the wire ends were still coated with the primer after being pulled in LN_2, just as in the ambient-air runs.

The effect of radiation on the EC-2273B/A potting compound was inconclusive in this test. Further tests are suggested. The data are plotted in Figure 6.32.

6.7 Sealants

Material O: EC-1949 (chemical composition proprietary)

At ambient-air temperature, the specimens tested satisfactorily, but apparently the elastomeric sealant failed to hold at the cryogen temperature. Specimens fell apart during submersion. No data were obtained on LN_2 controls and LN_2 low-dose postirradiation tests during April. The high-dose irradiation of this material was omitted in September since it was already obvious that it was not a good cryogenic specimen. The embrittled sealant did not hold the aluminum bars until test time, since no pull force could be detected on the Instron or Sanborn charts when specimens were pulled in the LN_2.

The EC-1949 showed definite degradation during ambient irradiations. It is suggested that changes in specimen configuration and modification of the test procedures be reviewed for the continuation of the testing of sealants in cryogenic fluids. Data that were obtained are plotted in Figure 6.33.

Material P: EC-1663 (chemical composition proprietary)

It was difficult to obtain good data points on the T-peel

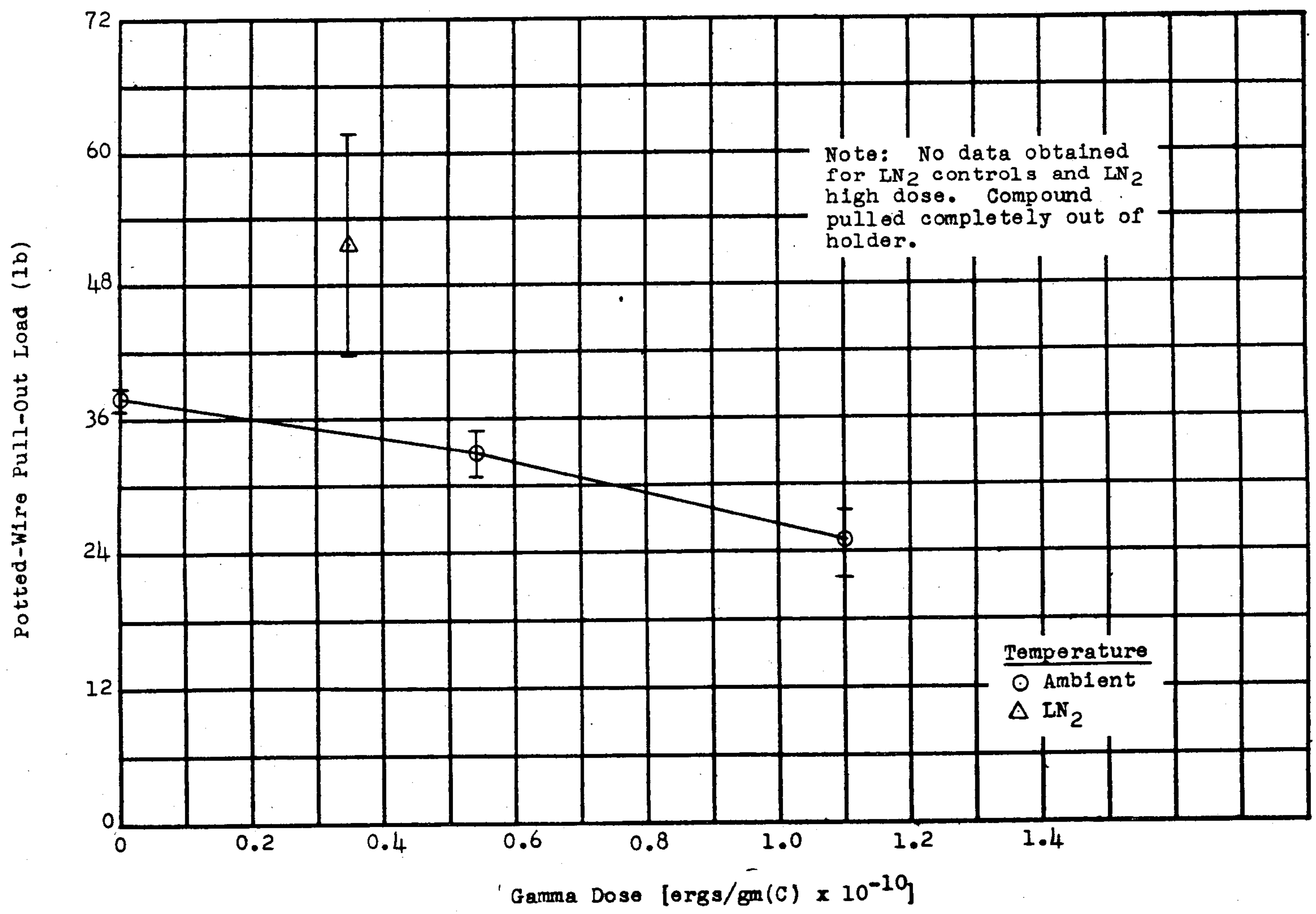


Figure 6.32 Potted-Wire Pull-Out Load vs Gamma Dose: EC-2273B/A (Potting Compound N)

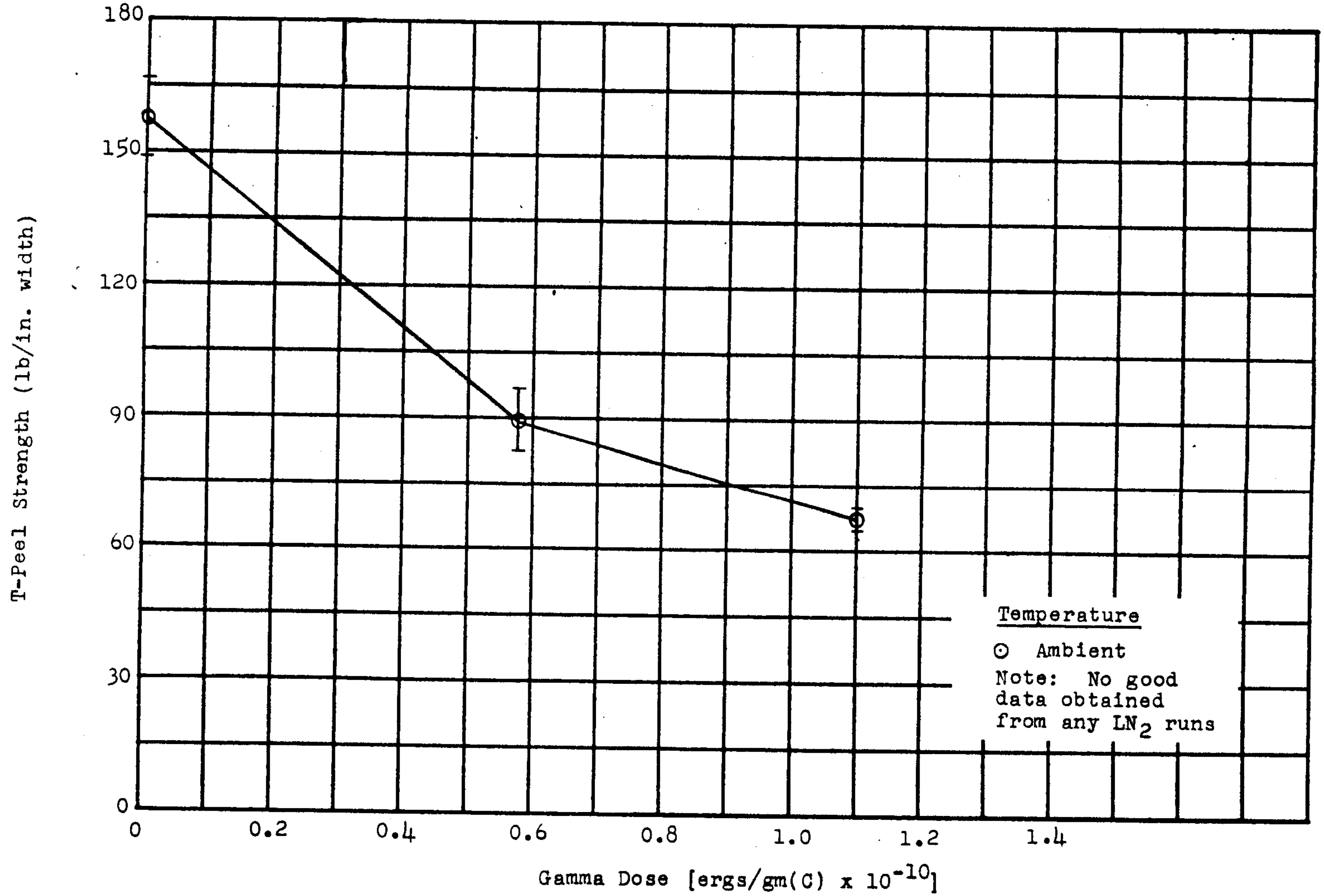


Figure 6.33 T-Peel Strength vs Gamma Dose: EC-1949 (Sealant O)

specimens. The ambient controls were all good, which showed that the method of preparation of the specimens was not the basic cause of the failures. T-peel strength of this material after irradiation at ambient-air temperature was less than one-fourth of its initial control value. EC-1663 was tested at all three LN_2 conditions, but no apparent breaks could be detected on the instrument charts. The low temperature and high radiation were too severe. Data obtained are plotted in Figure 6.34.

6.8 Thermal Insulations

Material F: CPR-20-2 (rigid foam)

Data obtained in thermal-conductivity tests of CPR-20-2 are plotted in Figure 6.35. Measured values of thermal conductivity are plotted as a function of temperature for both irradiated and unirradiated conditions. Also plotted are the manufacturer's corresponding data as received by telephone from Chemical Plastics Research Company.

The measured value of thermal conductivity for the unirradiated specimen was greater at room temperature than the value reported by the manufacturer and was, at LN_2 temperature, higher than the room-temperature value. This higher value at low temperature is opposite to the results that were expected, but was consistent in repeated runs. Definite conclusions as to the reasons for this have not been drawn, but there is evidence that one factor is, at least, partly responsible. A significant portion of heat generated in the test heater during low-temperature runs was apparently being drawn toward the ends of the tester rather than radially toward the outer

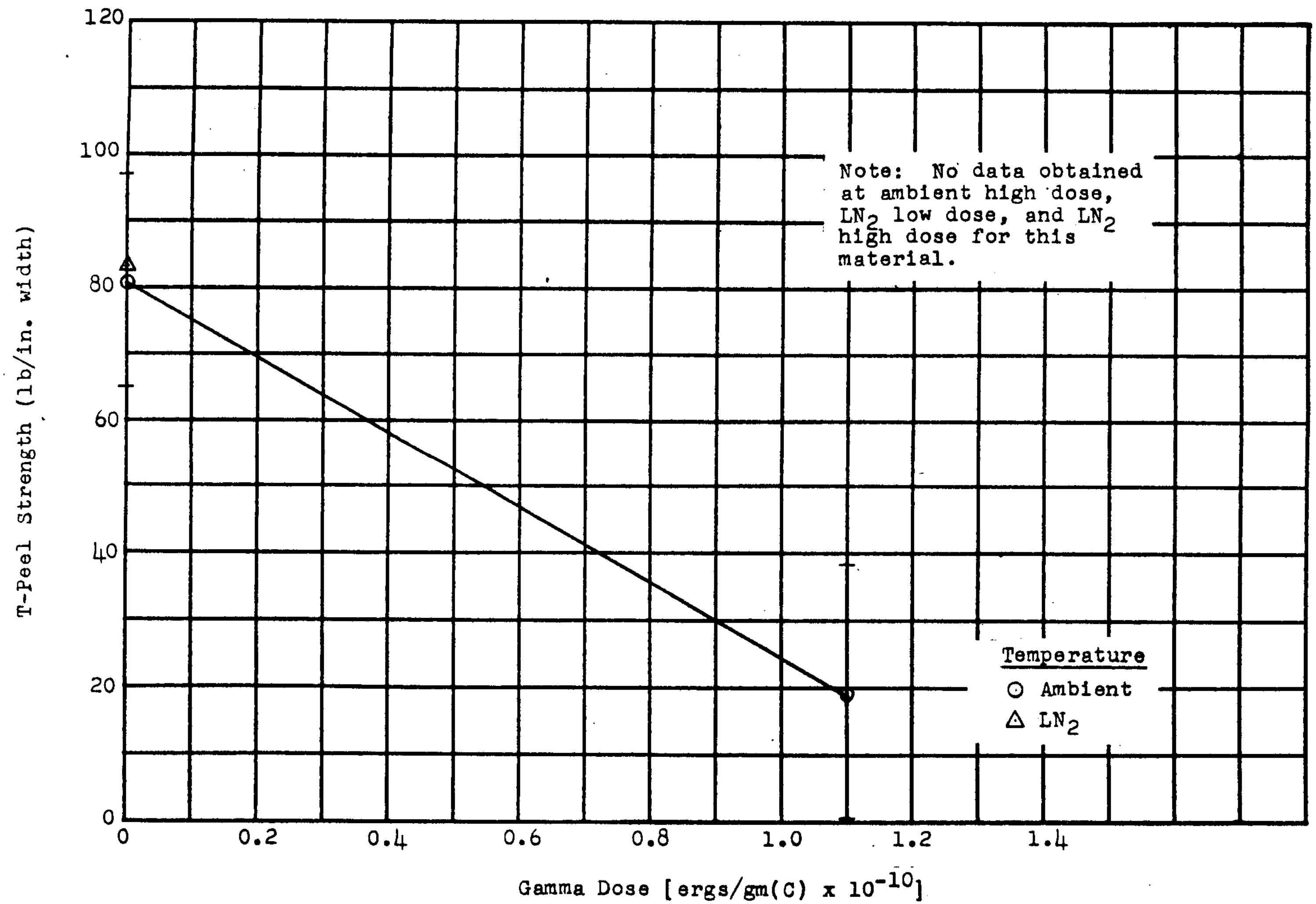


Figure 6.34 T-Peel Strength vs Gamma Dose: EC-1663 (Sealant P)

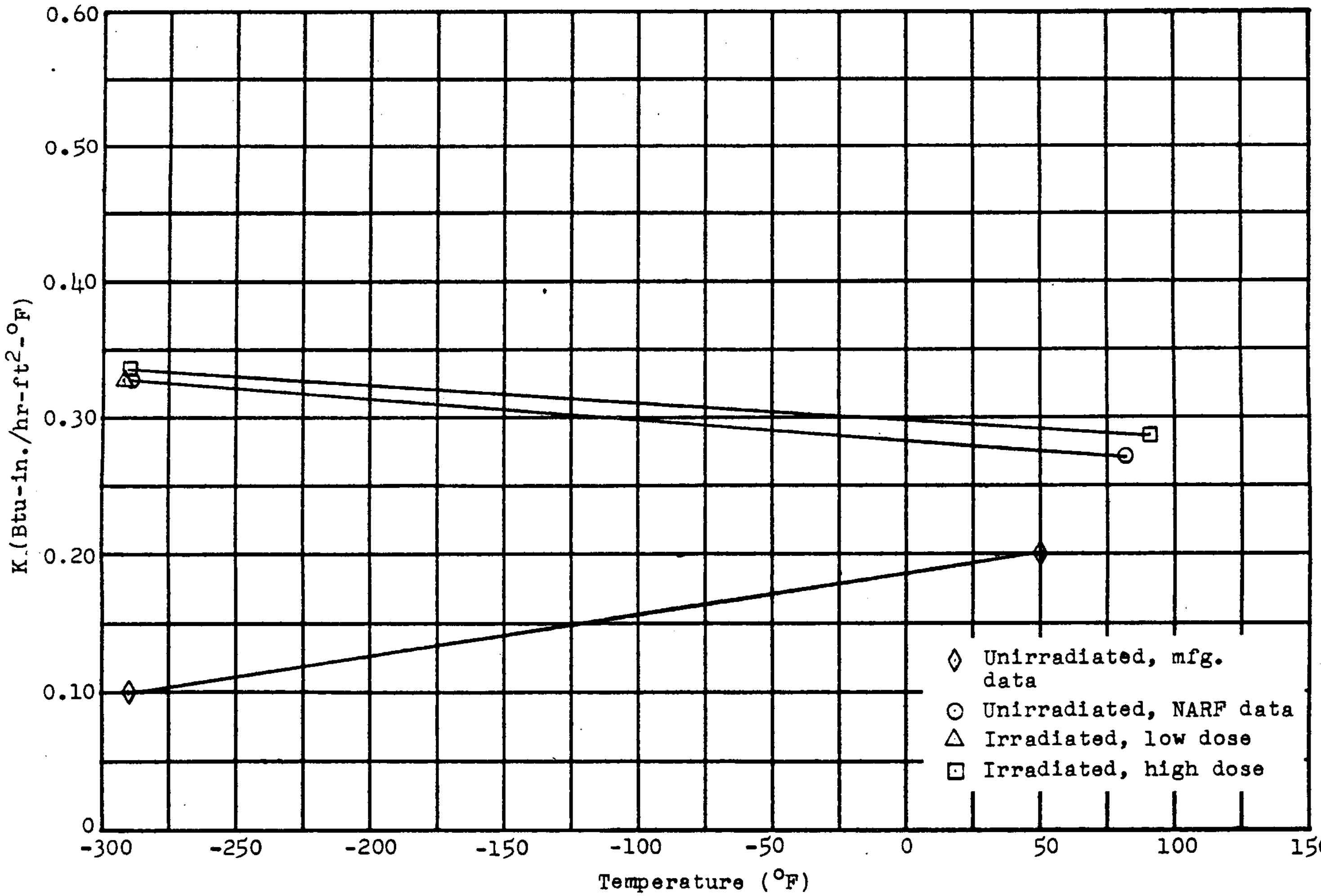


Figure 6.35 Thermal Conductivity vs Temperature: CPR-20-2 (Rigid Foam)

surface. This was thought to be a result of the existence of a relatively high value of thermal conductivity for the Mycalex used as heater core and end insulator in the tester. If time had permitted, substitution for the Mycalex of a material such as balsa wood could perhaps have reduced this heat loss to negligible values.

In Table 6.5 is the measured percentage change in the value of the coefficient of thermal conductivity as a function of both a low and a high dose of nuclear radiation. These percentages were obtained from a comparison with the unirradiated values measured at the same temperatures.

Table 6.5

Thermal Insulation CPR-20-2:
Measured Percentage Change in Coefficient of Thermal Conductivity for Two Irradiation Doses

Gamma Dose [ergs/gm(C)]	Test Temp (^{o}F)	Percent Increase in k after Irradiation
1×10^{9}	-291.6	0
1×10^{10}	+ 89.5*	5.1
1×10^{10}	-290.5	1.8

*Taken after irradiation upon returning of thermal conductivity tester to ambient-air temperature.

It should be noted that no ambient-air temperature value is shown for the foam after irradiation to a low dose. This was because the material was maintained at LN_2 temperature throughout the entire irradiation test, with an ambient-air value being obtained only after evaporation of all LN_2 at the end of the irradiation. This means, of course, that although the k-value measurement was made with the unit at ambient-air temperature, the radiation was incident under low-temperature conditions.

Absolute data obtained in the test are, after comparison to that reported by the manufacturer, highly questionable. However, considering that identical test conditions (including identical values for test and guard heater powers) were used for both pre- and postirradiation k-value measurements, it is felt that a reasonable indication of radiation effects (damage, or lack of damage) was established. Furthermore, there exists strong evidence that had one additional modification been made in the unit, i.e., the substitution of balsa wood for the Mycalex insulators, substantially better data could have resulted. It is hoped that further tests of this type will be authorized in 1964 to permit the inclusion of this added modification.

Despite the contrasts between the data obtained in the radiation tests and that reported by the manufacturer, a small amount of radiation damage (evidenced by an increase in the value of thermal conductivity) was demonstrated. The damage is considered small to the point of insignificance, however.

Material G: CPR-1021-2 (rigid foam)

Data obtained in thermal-conductivity tests of this material are plotted in Figure 6.36. Measured values of thermal conductivity are plotted as a function of temperature for both irradiated and unirradiated conditions. Also plotted are the manufacturer's corresponding data as received by telephone from Chemical Plastics Research Company.

The measured value of thermal conductivity for the unirradiated specimen was greater than that reported by the manufacturer,

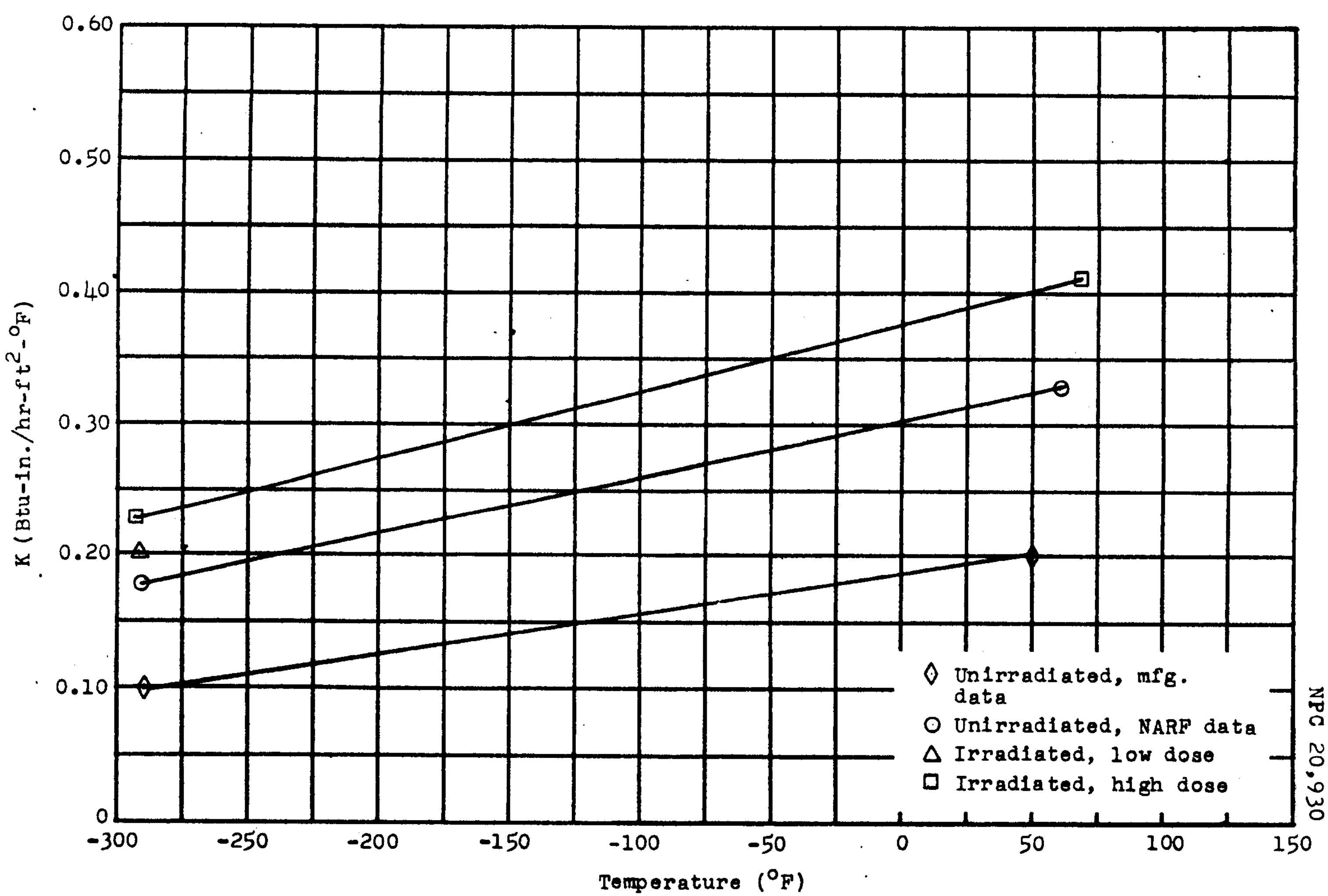


Figure 6.36 Thermal Conductivity vs Temperature: CPR-1021-2 (Rigid Foam)

both at room temperature and at LN_2 temperature. However, the thermal conductivity of this specimen, as measured in this test, decreased with a decrease in temperature, which was contrary to data obtained with the CPR 20-2. This downward trend in conductivity with lower temperatures is considered to be a result of a change in methods used for testing this unit.

Preliminary tests had shown that heat was also being drawn off the bottom end of the tester and, for reasons yet to be determined, was much greater in this unit than in the one containing CPR 20-2. To obtain the balance of temperatures on the ten inner thermocouples, as outlined in the original test procedure, an abnormally large amount of power was required for the bottom guard heater. Although this brought the thermocouple readings into balance, there were indications that a significant amount of heat from this guard heater was finding its way into the test-heater section and affecting the data accordingly.

As a final compromise for this condition, power to the bottom guard heater was increased to produce slightly higher readings from thermocouples at the top. This resulted in a slight flow of heat into the test-heater section - sufficient, in theory, to offset that which was flowing out of the test section at the bottom. Although the data thus produced more closely approximated that reported by the manufacturer, it was, of course, unacceptable as true absolute data.

It is felt that holding the established power for each of the heaters at the same level throughout both the pre- and postirradiation tests did, however, produce good relative data and thus serve to demonstrate the effects of radiation on the thermal conductivity of the foam. Figure 6.36 shows, as a result of irradiation, a significant increase in the value of thermal conductivity of the specimen at both ambient-air and LN_2 temperature. The measured percentage increase is shown in Table 6.6.

Table 6.6

Thermal Insulation CPR-1021-2:
Measured Percentage Changes in Coefficient of Thermal Conductivity for Two Irradiation Doses

Gamma Dose [ergs/gm(C)]	Test Temp (°F)	Percent Increase in k after Irradiation
1×10^9	-291.6	14.1
1×10^{10}	+ 67	25.1
1×10^{10}	-293	32.0

Again, as with the CPR 20-2 unit, it is believed that a substitution of balsa wood for the Mycalex would have produced substantially more reliable data as far as absolute measurements of thermal conductivity are concerned.

VII. CONCLUSIONS

Publication of this annual progress report marks the completion of the second year's work at NARF under NASA Contract NAS8-2450. Tests to measure the effects of nuclear radiation, cryotemperatures, and the combination of the two were performed on a series of non-metallic spacecraft materials.

Conclusions can be drawn regarding the test techniques, experimental test equipment, radiation sources, dosimetry measurements, materials tested, and test data.

7.1 Test Techniques and Experimental Equipment

Whenever possible, the appropriate ASTM specification was followed in performing the various engineering property tests on the material specimens. Several deviations from these specifications were necessary to accommodate the special test equipment used for the remotely performed tests on specimens submerged in liquid nitrogen. However, a consideration of the data to date leads to the conclusion that, despite these deviations, effects of radiation and cryotemperatures on the materials are clearly established.

The rather unusual dynamic test equipment used in these tests (detailed descriptions are given in Ref. 2) is, at this time, only two years old and will, as this work is continued in the future, be modified and improved. Potentialities for future developments in test apparatus of this kind are considered to be almost unlimited.

7.2 Radiation Source

The source of radiation for tests to date has been the Ground

Test Reactor (GTR), a heterogeneous, highly enriched, thermal nuclear reactor that produces a variety of radiation types, including fast and thermal neutrons, gamma photons, and beta rays. The fast-neutron flux ($E > 2.9$ Mev) at a reactor power level of 3 Mw varies from 9.0×10^9 to 4.3×10^{11} n/cm^2-sec. The thermal flux ($E < 0.48$ ev) is, for materials testing purposes, generally held to a minimum with the use of boral shields, and ranges from 3.6×10^9 to 6.3×10^9 n/cm^2-sec. The gamma dose rate at a 3-Mw power level varies from 3.6×10^4 to 1.0×10^6 ergs/gm(C)-sec.

7.3 Radiation Dosimetry

An accurate measure of radiation damage is, of course, useless without an accurate knowledge of the amount and character of the radiation causing the damage. The presently used system of foil detectors for neutron measurements is satisfactory in most respects. Improvements are being made, however, in detection arrangements on specimens to be irradiated and in the use of foils at extremely low and extremely high temperatures.

The accurate measurement of gamma radiation from a nuclear reactor has always been a problem. Various techniques are used, but the one most commonly used at NARF utilizes the so-called nitrous-oxide dosimeter. This method of measurement is accurate to $\pm$ 10% within a short range of temperatures above and below 70°F, but fails at extremely high or extremely low temperatures. In addition, it is cumbersome to handle and is quite fragile. Efforts to develop more accurate and versatile dosimeters will continue.

7.4 Materials

The cryogenic temperature of liquid nitrogen and/or the radiation from the GTR had a pronounced effect on most of the materials tested. These effects varied widely, from a definite improvement in mechanical properties of several plastics to an almost complete degradation of a few materials. A graphic summary of the effects of radiation and temperature on the adhesives, seals, electrical insulation, laminates, and one dielectric is presented in Figures 7.1, 7.2, and 7.3.

Of the two adhesives tested, the Aerobond 422J was the most stable when exposed to the combination environment. This is to be expected for an epoxy-phenolic. The ultimate tensile shear strength of the epoxy-nylon, Scotchweld AF-40, was reduced by temperature and radiation. These changes are illustrated by the bargraphs of Figure 7.1. Although the epoxy-phenolic 422J adhesive did not have as high an initial strength as did the epoxy-nylon AF-40, the retention of its properties warrants further consideration of this class of adhesive in the future.

As indicated in the discussion of results for the seal category, the static helium-gas sealing qualities of the Viton-B O-ring indicates it should be further evaluated in future tests. Polymer-SP, which is a relatively new plastic, has already received attention as a candidate plastic for aerospace applications. Figure 7.2 shows clearly that this polyimide polymer has exceptional merit after irradiation in liquid nitrogen. It should definitely be investigated further to see if this radiation and temperature resistance holds for other mechanical and physical properties.

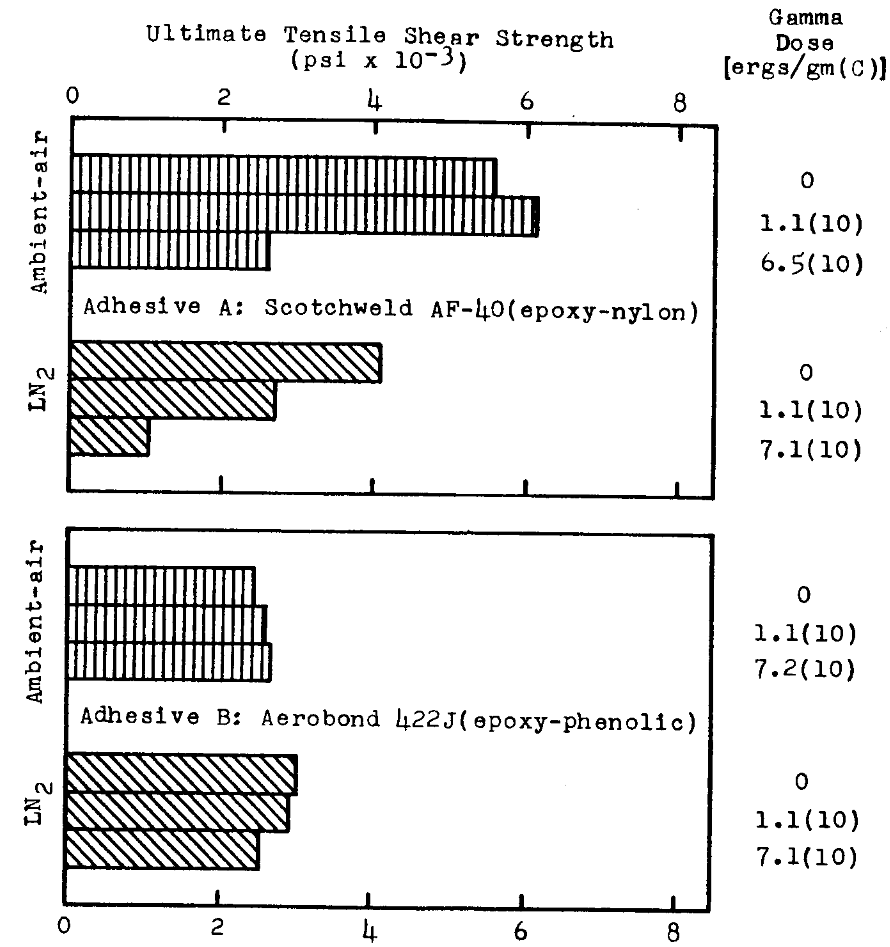


Figure 7.1 Effects of Radiation and Temperature on Ultimate Tensile Shear Strength of Adhesives

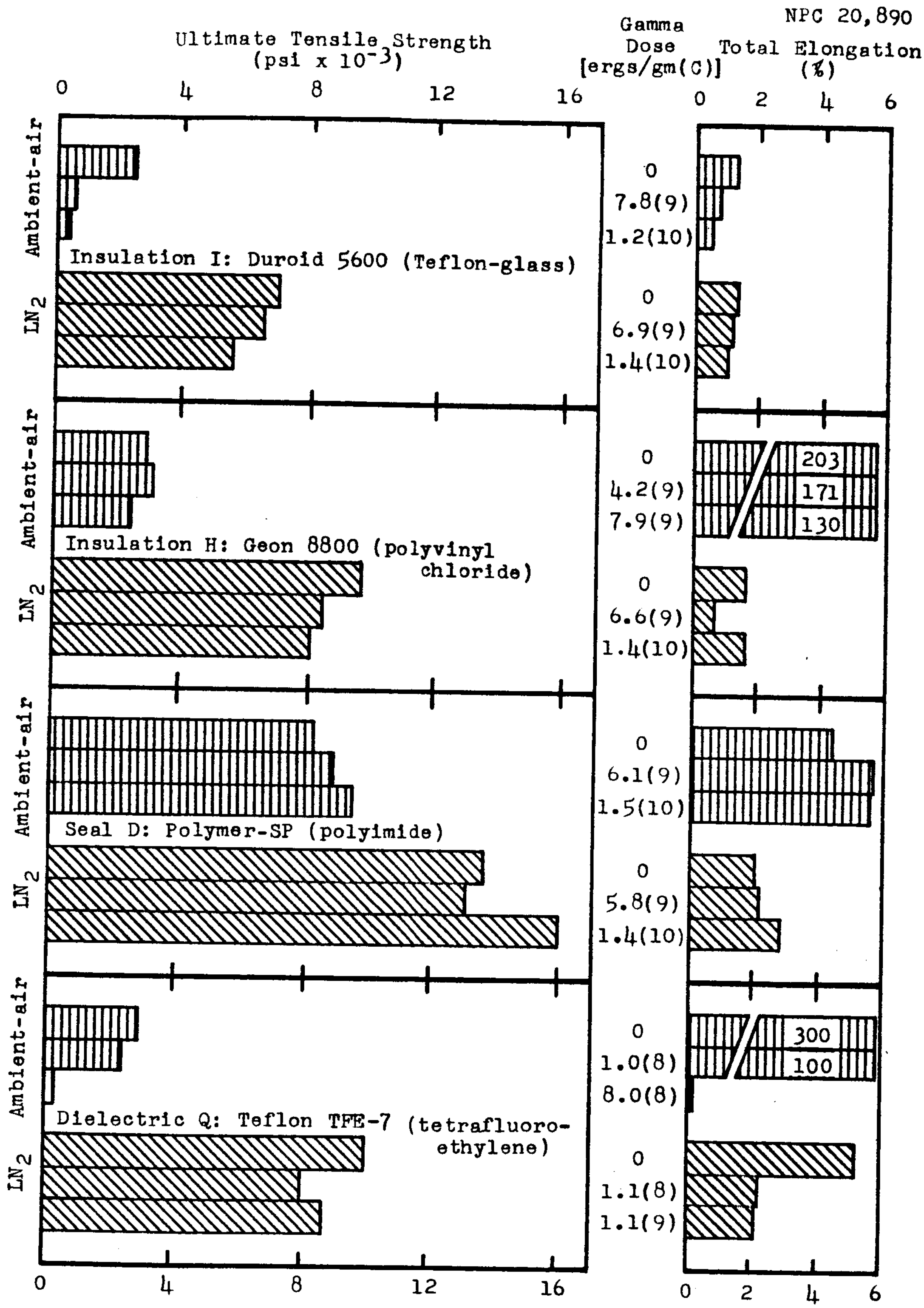


Figure 7.2 Effects of Radiation and Temperature on Ultimate Tensile Strength and Total Elongation of Electrical Insulation, Seals, and Dielectrics

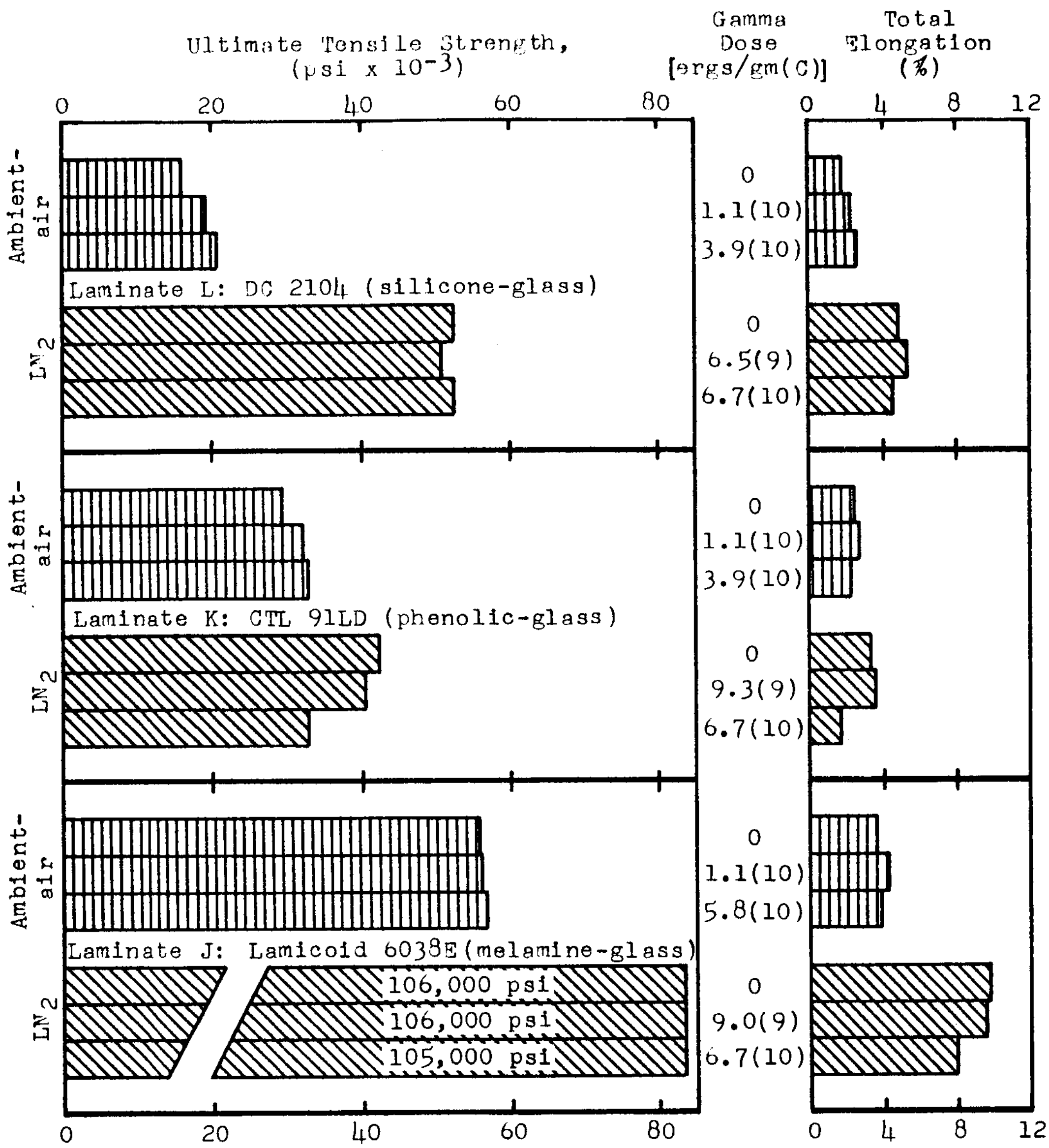


Figure 7.3 Effects of Radiation and Temperature on Ultimate Tensile Strength and Total Elongation of Laminates

The tensile properties of both Duroid 5600 electrical insulation (Teflon base) and Teflon TFE-7 were higher after the cryogenic irradiation than they were after the ambient air control and irradiation tests. Total elongation of Duroid 5600 specimens was virtually unchanged by radiation, but Teflon showed a reduction in this property with increasing radiation exposure. These trends are illustrated in Figure 7.2.

Although the ultimate tensile strength of Geon 8800 was changed only slightly as a result of irradiation, it is not recommended for further cryogenic irradiations because of its general degradation, including a color change from white to a dark greyish-pink, permanent embrittlement (loss of elongation), high retention of radioactivity, and an obnoxious odor.

All of the fiberglass-cloth, 1/8-in.-thick, multiple-layer laminates (silicone, phenolic, and melamine) exhibited excellent resistance to radiation. The ultimate tensile strength and percent total elongation of the control samples in liquid nitrogen both showed an increase over the same values recorded in ambient-air tests. In addition, these increases were retained by DC-2104 and Lamicoid 6038E up to the radiation exposure of 6.7×10^{10} ergs/gm(C) and by phenolic CTL-91LD to 9.3×10^{9} ergs/gm(C). The total elongation was also retained. Figure 7.3 presents a concise summary of these effects of radiation and temperature on these properties. Special note should be taken of the exceptionally high ultimate tensile strength of 106,000 psi for the Lamicoid 6038E during the cryogenic testing.

These three plastic laminates and the Polymer-SP should all be given radiation exposures beyond 7 x 10^{10} ergs/gm(C) at ambient and cryogenic temperatures to determine the actual threshold of damage, which seems to be above the level of the exposures given in this series of tests.

Tests for the potting compounds and sealants are now considered to have been somewhat less than judiciously selected. In some cases, for the wire-pull tests, the low tensile strength of the wire resulted in wire breaks prior to its being pulled out of the compound. The primer used with EC-2273 caused trouble by failing to adhere to the holder. The T-peel specimens separated in the LN_2 before they could be tested. These problems need to be analyzed for cause and effect. Modifications and revisions of the specimen configurations and/or test procedures will be instigated in future programs before the testing for radiation resistance of the potting compounds and sealants in the cryogenic environment is continued.

As indicated in the discussion of results for the thermal-conductivity test, the absolute data obtained in the tests are highly questionable. However, the prime requirement in the tests is considered to have been met, namely, to demonstrate the effects of radiation on the k-value of the materials. Since completion of the irradiation test, various plans have been formulated to improve the performance of the thermal-conductivity test apparatus. These planned modifications are expected to be incorporated into the testers in a 1964 carry-on of the program.

In conclusion, it should be emphasized that the behavior of the Polymer-SP and the Lamicoid 6038E melamine plastics was the most gratifying and encouraging of all materials tested within the categories of plastics. They should be included in the carry-on program for 1964. They should be of importance for aerospace applications if subsequent testing confirms the results included in this report.

APPENDIX A

DESCRIPTION OF MATERIALS IRRADIATED AND TESTED

Table A-1

Materials Used in Adhesive Tests

Code	Trade Name and Source	Material Description and Preparation of Stock Items
A	Resin. Scotchweld AF-40 (epoxy-nylon); Minn. Mining and Mfg. Co., Adhesives, Coatings, and Sealers Division, St. Paul, Minn. Source. Aluminum sheet supplied by NARF at GD/FW. Applied in lap-shear form at NASA, Huntsville, Alabama	Aluminum 2024-T3 adherent sheets, 6 in. wide and 1/16 in. thick, were supplied to NASA by NARF. At NASA, the adhesive was applied in accordance with the manufacturer's recommendations. The aluminum sheets were cleaned and a primer, EC-1956, applied to the faying surfaces and allowed to dry. The AF-40 was then applied and two sheets placed together with a 1/2-in. overlap. The samples were cured by heating from room temperature to 350°F and maintaining at 350°F for 1 hr under a bond pressure of 50 psi. The resin is reddish brown.
B	Resin. Aerobond 422J (epoxy-phenolic); Adhesives Engr. Co. Source. NARF at GD/FW	Skins of 2024T86 clad aluminum, 0.064 by 4 by 9 in., were cleaned with methyl ethyl ketone, vapor-degreased in trichloroethylene, heated in dichromate-sulfuric acid etch bath for 10 min at 150°F, then rinsed in distilled water. A strip of dry film adhesive was applied to one of the faying surfaces and the two skins placed together with a 1/2-in. overlap. The samples were cured by heating from room temperature to 350°F in 30 min and maintaining at 350°F for 1 hr under a bond pressure of 100 psi. The bonded adhesive is olive-green after cure.

Table A-2

Materials Used in Seal Tests

Code	Trade Name and Source	Material Description and Preparation of Stock Items
C	Elastomer. Viton B (copolymer of vinylidene fluoride and Hexafluoropropylene); E. I. DuPont Source. O-rings Precision 19007; Precision Rubber Co., Dayton, Ohio	Samples were in the shape of O-rings of uniform size No. 215; compound formulation is proprietary. Nominal dimensions were 1-1/16 by 1-5/16 by 1/8 in. Dimensions and tolerances were in accordance with specification MIL-P-5514, Rev. C. The elastomer is black.
D	Resin. Polymer SP-1 (polypryomellitimide); E. I. Du Pont Source. E. I. Du Pont	The SP-1 resin, with no filler, was molded in blocks under high pressure, then sawed into slabs approximately 1/4 by 1-1/2 by 10 in. The resin is dark chocolate brown. The Du Pont sample code is B-9053.

Table A-3

Materials Used in Thermal-Insulation Tests

Code	Trade Name and Source	Material Description and Preparation of Stock Items
E	Resin. Stafoam AA-402 (polyurethane); American Latex Products Corp. Source. American Latex Products Corp.	The resin and catalyst were supplied by American Latex Products as a R and T, two part, separately packaged product to be mixed according to the manufacturer's specifications and foamed-in-place. This material, a freon blown, polyether based, rigid polyurethane foam, is white with closed cells.
F	Resin. CPR-20-2 (polyurethane); CPR International Corp. Source. CPR (Chemical Plastics Research); International Corp., a division of Upjohn Corp.	This insulation, with a density of 2 lb/ft^3, was supplied by the manufacturer in rigid-foam blocks suitable for machining to size. It is a combination of the polyether and polyester resins and is carbon dioxide blown. The color is white.
G	Resin. CPR 1021-2 (polyurethane); CPR International Corp. Source. CPR International Corp., a division of Upjohn Corp., Torrance, California	This insulation was supplied as a rigid-foam block suitable for machining. The polyurethane is a polyfunctional polyether base resin, carbon-dioxide blown, having a density of 2 lb/ft^3. The color is white.

Table A-4

Materials Used in Electrical-Insulation and Electrical-Laminate Tests

Code	Trade Name and Source	Material Description and Preparation of Stock Items
H	Resin. Geon 8800 (polyvinyl chloride); B. F. Goodrich Chemical Co., A division of B. F. Goodrich Corp. Source. B. F. Goodrich Chemical Co., Akron, Ohio	This is a white, flexible, molded, elastomer-type plastic sheet of about 1/8-in. thickness in a 12-in. by 12-in. slab. The plasticizer is a polyester. Application is for wire and cable insulation.
I	Resin. Duroid 5600 (fiberglass-reinforced tetrafluoroethylene); Rodgers Corp., Rodgers, Conn. Source: Rodgers Corp., Rodgers, Conn.	This is a 1/8 in., brown, rigid, hard, pressboard sheet approximately 18 by 18 in. square. It is a press-molded, laminate-type sheet of Teflon filled with glass fibers. It has an appearance similar to that of masonite.
J	Resin. Lamicoid 6038E (melamine glass); Minn. Mining & Mfg. Co., Mico Division, Schenectady 1, N. Y. Source. Graco Supply Co., Fort Worth, Texas	Lamicoid 6038E is a new melamine, continuous-filament, glass-cloth laminate with greatly improved moisture-resistant characteristics, compared to previous glass melamine materials. It is a stock item of the Mico Division and was supplied as a laminate sheet 36 by 42 by 1/8 in.; NARF prepared the test items from this sheet. The general cure and preparation are not available but would be the standard for this item obtainable from 3M since it was a stock item. It was received from supplier April 1963. It is greyish-tan in color.

Table A-5

Materials Used in Structural Laminate Tests

Code	Trade Name, Type, Source	Material Description and Preparation of Stock Items
K	Resin. CTL-91LD (phenolic); American Reinforced Plastics Co., Los Angeles, Calif. Source. Eldon Fiberglass Mfg. Co., Compton, Calif., molder or laminator; Ironside Resins, Inc., mfg. of resin stock.	Special Order. This is a phenolic laminate of 38-in.-wide fiberglass 181 cloth, treated with Volan A (Batch No. S7-1) that meets the physical requirements of specification MIL-R 9299. It was supplied in 12- by 24- by 1/8-in. sheets. The liquid-resin stock was formulated by Ironside Resins, Inc., Columbus, Ohio; the fiberglass prepreg was prepared by the Coast Mfg. Co.; the stock was laminated by the Eldon Fiberglass Mfg. Co.; and the completed stock item was purchased from the American Reinforced Plastics Co., Los Angeles. Preparation and Cure. (From Eldon Fiberglass Operation Outline) CTL-91LD-181-Volan-38 in. prepreg per MSS 306, 12 plies 18 by 36 in. Set up mold in press; prepare mold; cut material as shown above in B/M; load (12) plies (stacked) in press and close; cure 1/2 hr at 300°F and 1/2 hr at 325°F with 20 tons on Dake press (applies 150 psi on part); post cure 1 hr at 200°F, 1 hr at 250°F, 1 hr at 300°F, and 2 hr at 350°F. Color is dark reddish-brown, and finished laminate is hard and rigid.
L	Resin. Dow Corning 2104 (silicone); Dow Corning, Midland, Mich. Source. Eldon Fiberglass Mfg. Co., Compton, Calif., molder or laminator; American Reinforced Plastics Co., stock materials.	Special Order. Fiberglass cloth 181, 38 in. wide, finish 112 Neutral ph., silicone resin content 43.4% (lot C-4554-1), Dow Corning catalyst XY-15, prepreg from Greige Goods. Finished size is 12- by 14- by 1/8-in. for laminate sheet and is white in color; laminate is rigid and hard. Preparation and Cure. Load 12 plies stacked in press, press-curing condition: 350°F for 30 min at 10 psi; oven-curing condition: 195°F for 16 hr, then 2 hr at each of the following temperatures, 260°F, 300°F, 350°F, and 390°F.

Table A-6

Materials Used in Potting Compound Tests

Code	Trade Name, Type, Source	Material Description and Preparation of Stock Item
M	Resin. Epon 828/Z (epoxy) epichlorohydrin/bisphenol, A-type; Shell Chemical Corp., New York Source. Shell Chemical Corp., Houston, Texas	The epoxy resin, Epon 828 was prepared with the manufacturer's catalyst type Z and potted in specially designed and machined pull jigs as shown under specimen description with the 22-gage electrical hookup wire embedded at both ends in the epoxy to a depth of 1/2 in. (further details under specimen preparation). Curing agent Z is a modified polyamine type. The optimum concentration of Epon Curing Agent Z for most applications is 20 phr (parts per 100 parts of resin). These specimens were prepared at NARF. Exact cure cycle not available, but curing cycles with Epon 828/Z system will vary considerably with application and size and shape of casting. Small castings based on Epon 828 can be cured satisfactorily in 2 hr at 175°F, followed by a post cure of 2 hr at 300°F. This is a small rigid casting (Shell Tech. Bul. SC: 56-79; SC-60-146).
N	Resin. EC-2273B/A (XS-1327148C; type is proprietary); Minn. Mining and Mfg., Co., Adhesives, Coatings & Sealers Div., St. Paul, Minn. Source. Minn. Mining and Mfg., Co., St. Paul, Minn.	EC-2273B/A is a solvent-free, synthetic elastomer. This potting compound is a two-part, heat-curing, potting and molding compound with Base B and curing agent A. Color is black. Mixing ratio is 20 parts of A to 100 parts B by weight. Rapid non-exotherm, cures are obtained at temperatures between 180°F and 250°F. The cured product is a tough, rubber-like compound. These test specimens were prepared by 3M's test laboratories under direction of Bill Rolke (St. Paul) and Stanley J. Slater (Dallas). Wire and mold were coated with a light-green primer (composition not given; company proprietary information).

Table A-7

Materials Used in Sealant Tests

Code	Trade Name, Type, Source	Material Description and Preparation of Stock Items
O	Resin. EC-1949 (proprietary); Minn. Mining and Mfg. Co., Adhesives, Coatings & Sealers Division, St. Paul, Minn. Source. Minn. Mining and Mfg. Co., St. Paul, Minn.	The material was applied according to the manufacturer's recommendations to 6-in.-wide adherent sheets of aluminum. The color is green. T-peel specimens were made from these sheets.
P	Resin. EC-1663 (RTV silicone); Minn. Mining and Mfg. Co., Adhesives, Coatings & Sealers Division, St. Paul, Minn. Source. Minn. Mining and Mfg. Co., St. Paul, Minn.	The material was applied according to the manufacturer's recommendations to 6-in.-wide adherent sheets of aluminum. The color is reddish-brown. T-peel specimens were made from these sheets.

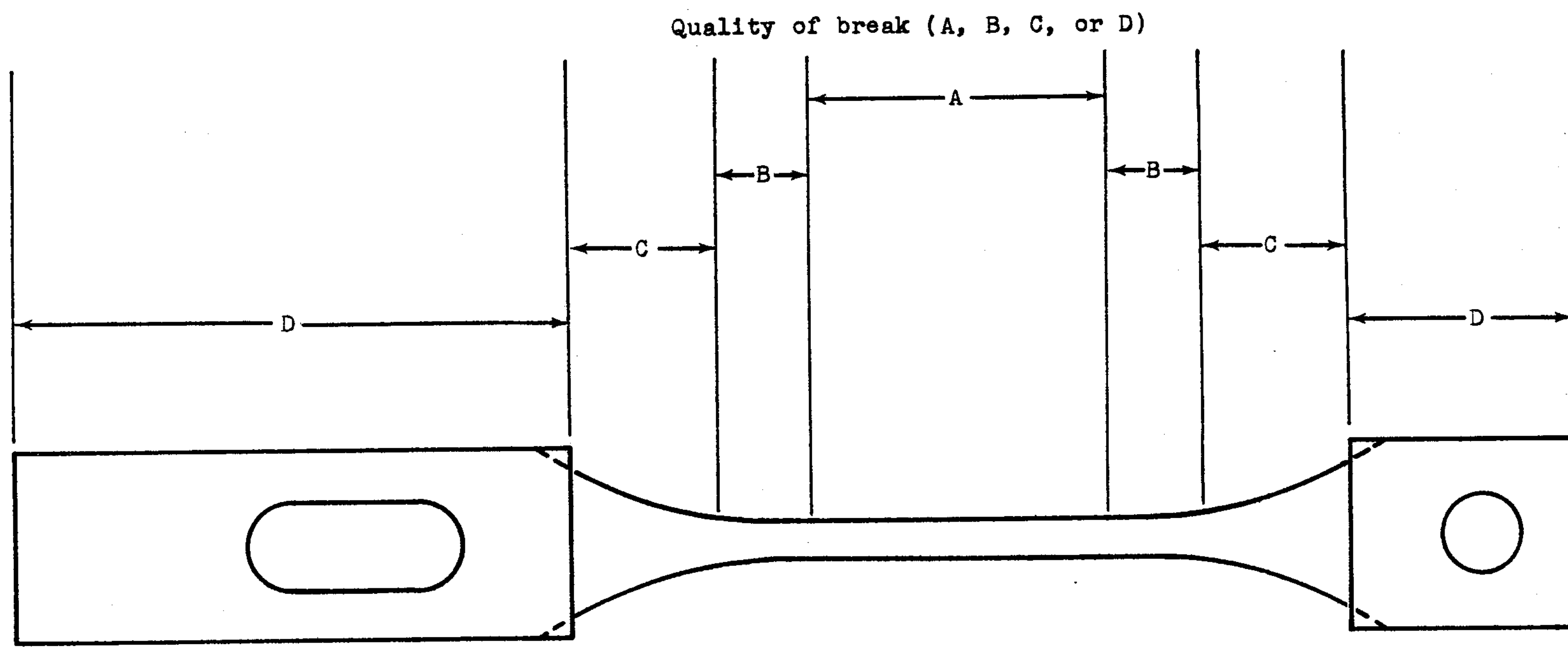
Table A-8

Material Used in Dielectric Tests

Code	Trade Name, Type, Source	Material Description and Preparation of Stock Item
Q	Resin. Teflon, TFE (tetrafluoroethylene); E. I. Du Pont, Plastics Department, Wilmington, Delaware Source. John L. Doré Co., P. O. Box 7772, Houston, Texas, for treated surface; and E. I. Du Pont for the Teflon.	This material is Teflon, TFE, Grade No. 7, electrical grade, molded by preforming-sintering technique and ram extruded. Since Teflon is difficult to bond to without treatment, the John L. Doré Company prepared the ends by special treatment in order to be able to bond the Al doublers to the Teflon. The material was received from Doré as individual slabs 1-1/4- by 10-1/2- by 1/8-in. ready for preparation of each test specimen. The areas treated were 3 in. on the long length and 1-1/2 in. on the short doubler end. The center gage section (5-1/2 in.) of test specimen was not treated. The surface had been treated by the etched processing technique. The Teflon was a white fluorocarbon with no filling or reinforcement material or binding agent; it was cut from molded sheet stock.

APPENDIX B

TABULATION OF DATA FOR MATERIALS IRRADIATED IN THE CRYOTEMPERATURE TEST PROGRAM



Note: See Figures 4.3 and 4.4 for detailed specimen drawings including dimensions.

Figure B-1 Specimen Break Code Description

Table B-1

Radiation-Cryotemperature Test Data: Scotchweld AF-40 (Material A)

Type of Test: Lap Shear

Type of Material: Adhesive

Date Irradiated	Date Tested	Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm^2) E < 0.48 ev	Neutron (n/cm^2) E > 2.9 Mev	Ult. Tensile Shear Strength (psi)	% Adhesive Failure	Specimen Color and Remarks
	5-13-63	A1-2	0.05	0	0 (Ambient-air Controls)	0	6630	60	Yellow
		A1-3	0.05				6340	20	Yellow
		A4-1	0.05				5590	30	Reddish Yellow
		A7-1	0.05				6310	90	Brownish Red
							6220/505	50/34	
	2-13-64	A1-5	0.05	0	0 (Ambient-air Controls)	0	5060	70	Yellow
		A2-1	0.05				6120	90	Reddish Brown
		A3-4	0.05				5520	70	Reddish Brown
		A3-5	0.05				5610	90	Reddish Brown
		A4-4	0.05				5520	95	Greenish Brown
		A4-5	0.05				5300	70	Greenish Brown
		A5-4	0.05				5060	30	Reddish Brown
		A5-5	0.05				4850	90	Reddish Brown
		A6-4	0.05				5940	70	Reddish Brown
		A6-5	0.05				4650	60	Reddish Brown
		A7-4	0.05				5150	30	Beige
		A7-5	0.05				4720	20	Beige
		A8-4	0.05				5800	60	Beige
		A8-5	0.05				5090	10	Beige
		A9-4	0.05				5220	30	Cream
		A9-5	0.05				5330	30	Cream
		A13-4	0.05				5020	30	Cream
		A13-5	0.05				4210	90	Cream
							5230/525	60/23	

Table B-1 (cont'd)

Radiation-Cryotemperature Test Data: Scotchweld AF-40 (Material A)

Type of Test: Lap Shear   Type of Material: Adhesive

Date Irradiated	Date Tested	Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm^2) $E < 0.48$ ev	Neutron (n/cm^2) $E > 2.9$ Mev	Ult. Tensile Shear Strength (psi)	% Adhesive Failure	Specimen Color and Remarks
	3-20-64	A2-2	0.05	0	0	0	6530	90	Reddish Cream
		A2-3	0.05	(Ambient-air Controls)			6750	90	Reddish Cream
		A10-1	0.05				5960	70	Yellow
		A10-2	0.05				5800	80	Yellow
		A10-3	0.05				5800	90	Yellow
		A10-4	0.05				5550	20	Yellow
		A10-5	0.05				5950	80	Yellow
		A11-1	0.05				5670	10	Yellow
		A11-2	0.05				5760	20	Yellow
		A11-3	0.05				6680	50	Yellow
		A11-4	0.05				6440	70	Yellow
		A11-5	0.05				6090	90	Yellow
		A12-1	0.05				5320	40	Reddish Yellow
		A12-2	0.05				5570	40	Reddish Yellow
		A12-3	0.05				4950	20	Reddish Yellow
		A12-4	0.05				5010	40	Reddish Yellow
		A12-5	0.05				5710	60	Reddish Yellow
							5860/502	55/22	
All Controls							5600/591		
4-25-63	5-13-63	A4-2	0.05	1.1(10)	1.0(14)	2.2(15)	6080	80	Greenish Yellow
		A9-1	0.05	(Ambient-air Low Dose)			6380	95	Greenish Yellow
		A13-1	0.05				6050	90	Greenish Yellow
							6170/195	90/9	

Table B-1 (cont'd)

Radiation-Cryotemperature Test Data: Scotchweld AF-40 (Material A)

Type of Test Lap Shear Type of Material Adhesive

Date Irradiated	Date Tested	Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure: Gamma [ergs/gm(C)]	Radiation Exposure: Neutron (n/cm^2) $E < 0.48$ ev	Radiation Exposure: Neutron (n/cm^2) $E > 2.9$ Mev	Ult. Tensile Shear Strength (psi)	% Adhesive Failure	Specimen Color and Remarks
4-25-63	5-13-63	A3-1 A4-3 A8-2	0.05 0.05 0.05	6.5(10)	3.3(14) (ambient-air High Dose)	3.7(16)	2210 2960 2700 2620/443	15 30 30 25/9	Brownish Yellow Brownish Yellow Brownish Yellow
	4-19-63	3-4-A1-1 3-5-A5-1 3-6-A8-1	0.023 0.005 0.025	0	0 (LN_2 Controls)	0	3000 5190 4140 4110/1294	100 100 100 100/0	Reddish Yellow Reddish Yellow Reddish Yellow
4-25-63	4-25-63	3-4-A13-2 3-5-A5-2 3-6-A7-2	0.029 0.032 0.032	1.1(10)	2.6(14) (LN_2 Low Dose)	1.4(15)	3400 2600 2170 2720/727	100 95 100 100/3	Yellow Yellow Yellow
9-13-63	9-13-63	3-4-A3-2 3-5-A5-3 3-6-A9-2	0.005 0.006 0.007	7.1(10)	8.0(14) (LN_2 High Dose)	1.3(16)	1470 1030 810 1100/390	100 100 100 100/0	Yellow Yellow Yellow

Table B-2

Radiation-Cryotemperature Test Data: Aerobond 422J (Material B)

Type of Test Lap Shear Type of Material Adhesive

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Ult. Tensile Shear Strength (psi)	% Adhesive Failure	Specimen Color and Remarks
Irradiated	Tested			Gamma [ergs/gm(C)]	Neutron (n/cm^2) $E < 0.48$ ev	Neutron (n/cm^2) $E > 2.9$ Mev			
	5-13-63	B1-5 B2-2 B3-5 B4-3	0.05 0.05 0.05 0.05	0	0 (Ambient-air Controls)	0	2480 2490 2560 2610 2540/63	10 90 90 10 50/39	Olive Drab Olive Drab Olive Drab Olive Drab
	2-13-64	B1-2 B2-4 B3-3 B4-8	0.05 0.05 0.05 0.05	0	0 (Ambient-air Controls)	0	2230 2370 2410 2240 2310/63	10 90 90 20 50/39	Olive Green Olive Green Olive Green Olive Green
4-25-63	5-13-63	B1-3 B1-4 B2-3	0.05 0.05 0.05	1.1(10)	1.1(14) (Ambient-air Low Dose)	2.2(15)	2390 2620 2560 2520/136	5 10 90 35/50	Olive Drab Olive Drab Olive Drab
4-25-63	5-13-63	B2-5 B3-4 B4-4	0.05 0.05 0.05	7.2(10)	5.3(14) (Ambient-air High Dose)	3.3(16)	2470 2650 2460 2530/112	70 20 5 30/38	Dark Brownish Green
	4-19-63	3-1-B1-1 3-2-B3-1 3-3-B4-1	0.086 0.023 0.025	0	0 (LN_2 Controls)	0	3060 3100 2940 3030/95	90 90 90 90/0	Olive Green Olive Green Olive Green

Table B-2 (cont'd)

Radiation-Cryotemperature Test Data: Aerobond 422J (Material B)

Type of Test Lap Shear Type of Material Adhesive

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Ult. Tensile Shear Strength (psi)	% Adhesive Failure	Specimen Color and Remarks
Irradiated	Tested			Gamma [ergs/gm(C)]	Neutron (n/cm^2) E < 0.48 ev	Neutron (n/cm^2) E > 2.9 Mev			
4-25-63	4-25-63	3-1-B4-5 3-2-B2-6 3-3-B3-6	0.008 0.006 0.003	1.1(10) (LN_2	2.6(14) Low Dose)	1.4(15)	2510 2800 3410 2910/532	90 90 90 90/0	Brownish Green Brownish Green Brownish Green
9-13-63	9-13-63	3-1-B1-6 3-2-B2-1 3-3-B4-6	0.011 0.005 0.005	7.1(10) (LN_2	8.0(14) High Dose)	1.3(16)	2170 3030 2420 2540/509	98 98 98 98/0	Brownish Green Brownish Green Brownish Green

Table B-3

Radiation-Cryotemperature Test Data: Polymer-SP (Material D)

Type of Test Ambient-Air Controls

Type of Material Seal

Ult. Tensile Strength (avg) 8,410/966 psi
Total Elongation (avg):
Crosshead (4.0-in. gage length) 3.65 %
Extensometer (2.0-in. gage length) 2.97 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 5-20-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron (E < 0.48 ev) 0 n/cm^2
Neutron (E > 2.9 Mev) 0 n/cm^2

Date of Irradiation Not Applicable

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0645 sq in.				Quality of Break A Pull Speed 0.05 in./min Area 0.0653 sq in.				Quality of Break C Pull Speed 0.05 in./min Area 0.0644 sq in.				Quality of Break C Pull Speed 0.05 in./min Area 0.0657 sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
155	0.010	0.25	0.03	460	0.010	0.25	0.10	544	0.010	0.25	0.09	533	0.010	0.25	0.08
759	0.020	0.50	0.15	1,230	0.020	0.50	0.28	1,370	0.020	0.50	0.26	1,340	0.020	0.50	0.26
1,630	0.030	0.75	0.35	2,140	0.030	0.75	0.48	2,170	0.030	0.75	0.45	2,180	0.030	0.75	0.47
2,400	0.040	1.00	0.55	2,990	0.040	1.00	0.68	2,950	0.040	1.00	0.64	2,970	0.040	1.00	0.68
3,180	0.050	1.25	0.75	3,750	0.050	1.25	0.88	3,650	0.050	1.25	0.84	3,760	0.050	1.25	0.91
3,950	0.060	1.50	0.96	4,490	0.060	1.50	1.10	4,300	0.060	1.50	1.05	4,420	0.060	1.50	1.15
4,600	0.070	1.75	1.20	5,100	0.070	1.75	1.31	4,970	0.070	1.75	1.27	5,040	0.070	1.75	1.39
5,150	0.080	2.00	1.40	5,740	0.080	2.00	1.54	5,510	0.080	2.00	1.48	5,540	0.080	2.00	1.60
5,770	0.090	2.25	1.64	6,310	0.090	2.25	1.77	6,060	0.090	2.25	1.71	6,140	0.090	2.25	1.86
6,280	0.100	2.50	1.85	6,820	0.100	2.50	1.99	6,520	0.100	2.50	1.91	6,550	0.100	2.50	2.07
7,360	0.125	3.13	2.34	7,080	0.105	2.63	2.10	7,380	0.120	3.00	2.30	7,020	0.110	2.75	2.25
8,370	0.150	3.75	2.93					8,150	0.140	3.50	2.73	7,950	0.130	3.25	2.73
9,070	0.170	4.25	3.41					8,510	0.150	3.75	2.95	8,330	0.140	3.50	2.98
								8,880	0.160	4.00	3.20	8,450	0.143	3.58	3.04
								9,040	0.165	4.13	3.31				

Table B-3 (cont'd)

Radiation-Cryotemperature Test Data: Polymer-SP (Material D)

Type of Test Ambient-Air Controls

Type of Material Seal

Ult. Tensile Strength (avg) 8,400/1,150 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 5.59 %
Extensometer (2.0-in. gage length) Not Available %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 9-27-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron (E < 0.48 ev) 0 n/cm^2
Neutron (E > 2.9 Mev) 0 n/cm^2

Date of Irradiation Not Applicable

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break A Pull Speed 0.05 in./min Area 0.0315 sq in.				Quality of Break A Pull Speed 0.05 in./min Area 0.0338 sq in.				Quality of Break Pull Speed in./min Area sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0								
381	0.020	0.57	0.08	533	0.020	0.57	0.15								
698	0.030	0.86	0.14	976	0.030	0.86	0.25								
1,080	0.040	1.14	0.22	1,480	0.040	1.14	0.37								
2,060	0.060	1.71	0.45	2,010	0.050	1.43	0.52								
3,210	0.080	2.29	0.75	2,510	0.060	1.71	0.67								
4,350	0.100	2.86	1.14	3,110	0.070	2.00	0.86								
4,920	0.110	3.14	1.35	3,700	0.080	2.29	1.05								
5,330	0.120	3.43	1.58	4,230	0.090	2.57	1.26								
6,190	0.140	4.00	2.06	4,730	0.100	2.86	1.51								
6,660	0.150	4.29	2.30	5,210	0.110	3.14	1.73								
6,980	0.160	4.57	2.56	5,680	0.120	3.43	1.99								
7,940	0.190	5.43	----	6,070	0.130	3.71	2.22								
8,410	0.200	5.71	----	6,510	0.140	4.00	2.51								
8,730	0.210	6.00	----	6,890	0.150	4.29	2.79								
9,050	0.221	6.31	----	7,750	0.170	4.86	----								

Table B-3 (cont'd)

Radiation-Cryotemperature Test Data: Polymer-SP (Material D)

Type of Test: Ambient-Air Low Dose

Type of Material: Seal

Ult. Tensile Strength (avg) 8,990/898 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 5.94 %
Extensometer (2.0-in. gage length) Not Available %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 9-27-63

Radiation Exposure:
Gamma 6.1(9) ergs/gm(C)
Neutron (E < 0.48 ev) 5.5(13) n/cm^2
Neutron (E > 2.9 Mev) 8.3(14) n/cm^2

Date of Irradiation 9-13-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break A Pull Speed 0.05 in./min Area 0.0319 sq in.				Quality of Break A Pull Speed 0.05 in./min Area 0.0306 sq in.				Quality of Break A Pull Speed 0.05 in./min Area 0.0310 sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0				
94	0.010	0.29	0.03	490	0.020	0.57	0.10	387	0.020	0.57	0.08				
471	0.020	0.57	0.11	1,470	0.040	1.14	0.30	1,360	0.040	1.14	0.29				
942	0.030	0.86	0.22	2,610	0.060	1.71	0.58	2,450	0.060	1.71	0.57				
1,510	0.040	1.14	0.35	3,010	0.070	2.00	0.74	3,070	0.070	2.00	0.74				
2,130	0.050	1.43	0.53	3,760	0.080	2.29	0.93	3,650	0.080	2.29	0.94				
2,820	0.060	1.71	0.71	4,340	0.090	2.57	1.15	4,780	0.100	2.86	1.37				
3,450	0.070	2.00	0.93	4,900	0.100	2.86	1.40	5,810	0.120	3.43	1.91				
4,080	0.080	2.29	1.14	5,420	0.110	3.14	1.66	6,230	0.130	3.71	2.13				
4,680	0.090	2.57	1.38	5,880	0.120	3.43	1.92	6,650	0.140	4.00	2.35				
5,180	0.100	2.86	1.62	6,310	0.130	3.71	2.20	7,030	0.150	4.29	2.53				
5,650	0.110	3.14	1.89	6,730	0.140	4.00	2.48	7,360	0.160	4.57	2.65				
6,530	0.130	3.71	2.44	7,150	0.150	4.29	2.79	7,580	0.170	4.86	----				
6,870	0.140	4.00	2.69	7,510	0.160	4.57	3.09	8,710	0.200	5.71	----				
7,310	0.170	4.86	----	8,170	0.180	5.14	----	9,290	0.220	6.29	----				
8,350	0.181	5.17	----	8,760	0.198	5.66	----	9,870	0.245	7.00	----				

Table B-3 (cont'd)

Radiation-Cryotemperature Test Data: Polymer-SP (Material D)

Type of Test Ambient-Air High Dose

Type of Material Seal

Ult. Tensile Strength (avg) 10,100/X psi
Total Elongation (avg):
Crosshead (4.0-in. gage length) 4.83 %
Extensometer (2.0-in. gage length) 4.30 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 5-20-63

Radiation Exposure:
Gamma 1.1(10) ergs/gm(C)
Neutron (E < 0.48 ev) 1.2(14) n/cm^2
Neutron (E > 2.9 Mev) 2.2(15) n/cm^2

Date of Irradiation 4-25-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0645 sq in.				Quality of Break Pull Speed in./min Area sq in.				Quality of Break Pull Speed in./min Area sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0												
852	0.020	0.50	0.15												
1,670	0.030	0.75	0.30												
2,560	0.040	1.00	0.50												
3,360	0.050	1.25	0.75												
4,730	0.070	1.75	1.20												
5,410	0.080	2.00	1.45												
6,510	0.100	2.50	2.00												
6,980	0.110	2.75	2.25												
7,440	0.120	3.00	2.45												
8,230	0.140	3.50	2.90												
8,990	0.160	4.00	3.40												
9,350	0.170	4.25	3.70												
9,700	0.180	4.50	3.95												
9,980	0.190	4.75	4.25												
10,100	0.193	4.83	4.30												

Table B-3 (cont'd)

Radiation-Cryotemperature Test Data: Polymer-SP (Material D)

Type of Test Ambient-Air High Dose

Type of Material Seal

Ult. Tensile Strength (avg) 9,270/319 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 5.63 %
Extensometer (2.0-in. gage length) Not Available %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 9-27-63

Radiation Exposure:
Gamma 1.5(10) ergs/gm(C)
Neutron (E < 0.48 ev) 7.0(13) n/cm^2
Neutron (E > 2.9 Mev) 1.8(15) n/cm^2

Date of Irradiation 9-13-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0320 sq in.				Quality of Break A Pull Speed 0.05 in./min Area 0.0330 sq in.				Quality of Break Pull Speed in./min Area sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0								
469	0.020	0.57	0.09	91	0.020	0.57	0.04								
1,340	0.040	1.14	0.26	242	0.040	1.14	0.08								
1,940	0.050	1.43	0.39	848	0.060	1.71	0.21								
2,560	0.060	1.71	0.54	1,270	0.070	2.00	0.34								
3,810	0.080	2.29	0.89	3,690	0.080	2.29	0.48								
4,440	0.090	2.57	1.09	4,300	0.090	2.57	0.63								
5,030	0.100	2.86	1.33	4,880	0.100	2.86	0.82								
5,560	0.110	3.14	1.56	5,390	0.110	3.14	1.01								
6,060	0.120	3.43	1.82	5,880	0.120	3.43	1.22								
6,500	0.130	3.71	2.06	6,300	0.130	3.71	1.43								
6,970	0.140	4.00	2.35	6,750	0.140	4.00	1.56								
7,380	0.150	4.29	2.64	7,150	0.150	4.29	1.82								
7,970	0.170	4.86	----	7,720	0.170	4.86	2.15								
8,470	0.180	5.14	----	8,210	0.180	5.14	2.25								
9,090	0.197	5,63	----	9,450	-----	----	----								

Table B-4

Radiation-Cryotemperature Test Data: Polymer-SP (Material D)

Type of Test LN2 Controls   Type of Material Seal

Ult. Tensile Strength (avg) 13,700/1,830 psi
Total Elongation (avg):
Pull Rod (3.5-in. gage length) 2.08 %
Pull Rod Speed at Break (avg) 0.019 in./min
Pull Assembly Unit East
Date of Tensile Test 8-2-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron(E < 0.48 ev) 0 n/cm^2
Neutron(E > 2.9 Mev) 0 n/cm^2

Date of Irradiation Not Applicable

Specimen 1			Specimen 2			Specimen 3		
Rod 1 Position 1 Quality of Break A Rod Speed 0.017 in./min Area 0.0318 sq in.			Rod 1 Position 2 Quality of Break A Rod Speed 0.019 in./min Area 0.0323 sq in.			Rod 1 Position 3 Quality of Break A Rod Speed 0.021 in./min Area 0.0324 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
1,830	0.008	0.23	1,120	0.007	0.10	1,790	0.011	0.31
3,080	0.015	0.43	2,450	0.015	0.43	3,370	0.019	0.54
4,220	0.022	0.63	3,940	0.022	0.63	4,910	0.025	0.71
5,850	0.028	0.80	5,480	0.028	0.80	6,330	0.034	0.97
7,110	0.035	1.00	7,100	0.037	1.06	8,560	0.044	1.26
8,060	0.041	1.17	9,170	0.047	1.34	10,200	0.055	1.57
9.250	0.049	1.40	10,500	0.055	1.57	11,900	0.062	1.77
10,900	0.056	1.60	12,100	0.065	1.86			
12,100	0.064	1.83	14,100	0.074	2.11			
13,500	0.073	2.09						
15,000	0.083	2.37						

*Based on pull-rod travel

Table B-4 (cont'd)

Radiation-Cryotemperature Test Data: Polymer-SP (Material D)

Type of Test LN$_2$ Low Dose

Type of Material Seal

Ult. Tensile Strength (avg) 13,100/1,540 psi
Total Elongation (avg):
Pull Rod (3.5-in. gage length) 2.01 %
Pull Rod Speed at Break (avg) 0.027 in./min
Pull Assembly Unit East
Date of Tensile Test 9-10-63

Radiation Exposure:
Gamma 5.8(9) ergs/gm(C)
Neutron(E < 0.48 ev) 8.3(13) n/cm^2
Neutron(E > 2.9 Mev) 1.2(15) n/cm^2

Date of Irradiation 9-10-63

Specimen 1			Specimen 2			Specimen 3		
Rod 1 Position 1 Quality of Break C Rod Speed 0.025 in./min Area 0.0315 sq in.			Rod 1 Position 3 Quality of Break C Rod Speed 0.028 in./min Area 0.0324 sq in.			Rod 1 Position 4 Quality of Break C Rod Speed 0.027 in./min Area 0.0320 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
2,220	0.007	0.20	618	0.007	0.20	531	0.004	0.11
4,300	0.013	0.37	1,360	0.012	0.34	1,470	0.012	0.34
5,870	0.021	0.60	2,630	0.018	0.51	2,880	0.019	0.54
6,670	0.028	0.80	3,980	0.024	0.69	3,970	0.024	0.69
8,570	0.034	0.97	4,970	0.030	0.86	5,125	0.030	0.86
9,910	0.043	1.23	6,180	0.036	1.03	6,250	0.037	1.06
11,300	0.051	1.46	7,200	0.042	1.20	7,500	0.043	1.23
12,400	0.059	1.69	8,620	0.047	1.34	8,970	0.049	1.40
13,800	0.065	1.86	9,980	0.055	1.57	10,200	0.057	1.63
			11,300	0.063	1.80	11,500	0.066	1.89
			12,700	0.072	2.06			
			14,100	0.080	2.29			

*Based on pull-rod travel

Table B-4 (cont'd)

Radiation-Cryotemperature Test Data: Polymer-SP (Material D)

Type of Test LN2 High Dose | Type of Material Seal

Ult. Tensile Strength (avg) 16,000/3,550 psi
Total Elongation (avg):
Pull Rod (3.5 -in. gage length) 2.86 %
Pull Rod Speed at Break (avg) 0.033 in./min
Pull Assembly Unit East
Date of Tensile Test 9-11-63

Radiation Exposure:
Gamma 1.4(10) ergs/gm(C)
Neutron (E < 0.48 ev) 2.7(14) n/cm^2
Neutron (E > 2.9 Mev) 3.2(15) n/cm^2
Date of Irradiation 9-11-63

Specimen 1			Specimen 2			Specimen 3		
Rod ___ Position ___ Quality of Break ___ Rod Speed ___ in./min Area ___ sq in.			Rod 7 Position 2 Quality of Break C Rod Speed 0.029 in./min Area 0.0330 sq in.			Rod 7 Position 4 Quality of Break C Rod Speed 0.037 in./min Area 0.0319 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
			0	0	0	0	0	0
			1,210	0.005	0.14	1,440	0.023	0.66
			2,120	0.011	0.31	2,890	0.035	1.00
			3,390	0.017	0.49	4,550	0.042	1.20
			4,880	0.024	0.69	6,090	0.050	1.43
			6,210	0.032	0.91	7,940	0.059	1.69
			7,870	0.040	1.14	9,880	0.070	2.00
			9,450	0.047	1.34	11,400	0.081	2.31
			11,100	0.056	1.60	13,300	0.093	2.66
			12,700	0.064	1.83	14,900	0.104	2.97
			14,000	0.074	2.11	16,800	0.114	3.26
						18,000	0.126	3.60

*Based on pull-rod travel

Table B-5 (Rejections)

Radiation-Cryotemperature Test Data: Polymer-SP (Material D)

Type of Test Tensile Type of Material Seal

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Ultimate Tensile Strength (psi)	Comments
Irradiated	Tested			Gamma [ergs/gm(C)]	Neutron (n/cm^2) E < 0.48 ev	Neutron (n/cm^2) E > 2.9 Mev		
	8-14-63	0-X-1	0.05	0	0	0	10,100	No extensometer used
				(Ambient-air Controls)				
4-25-63	5-20-63	1-N1-1 1-N1-2 1-N1-3	0.05 0.05 0.05	6.1(9)	5.9(13)	1.2(15)	8,730 9,190 8,950	All bad breaks at one of the doublers. Wide specimens.
				(Ambient-air Low Dose)				
4-25-63	5-20-63	2-N1-2 2-N1-3	0.05 0.05	1.1(10)	1.2(14)	2.2(15)	8,560 7,090	Bad breaks. Cross section too large.
				(Ambient-air High Dose)				
9-13-63	9-27-63	1-E3-1	0.05	1.5(10)	7.0(13)	1.8(15)	6,460	Bad specimen. Not representative data.
				(Ambient-air High Dose)				
	4-19-63	2-1-WX 2-2-WX 2-3-WX	0.028 0.034 0.035	0	0	0	9,990 9,350 8,840	Bad breaks. Cross section too large.
				(LN_2 Controls)				
4-25-63	4-25-63	2-1-WW 2-2-WW 2-3-WW	0.019 0.021 0.023	5.4(9)	1.6(14)	7.6(14)	8,160 10,100 10,800	Very bad adhesive failure. No doublers stayed on.
				(LN_2 Low Dose)				
9-11-63	9-11-63	7-1-EN	0.029	1.4(10)	2.7(14)	3.2(15)	No Values	Ice formation on rod ruined data.
				(LN_2 High Dose)				

Table B-6

Radiation-Cryotemperature Test Data: Geon 8800 (Material H)

Type of Test: Ambient-air Controls

Type of Material: Electrical Insulation

Ult. Tensile Strength (avg) 3,000/112 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 203 %
Extensometer (2.0-in. gage length) 201 %
Crosshead Pull Speed 0.20 in./min
Date of Tensile Test 9-30-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron (E < 0.48 ev) 0 n/cm^2
Neutron (E > 2.9 Mev) 0 n/cm^2

Date of Irradiation: Not Applicable

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break A Pull Speed 0.20 in./min Area 0.0247 sq in.				Quality of Break A Pull Speed 0.20 in./min Area 0.0248 sq in.				Quality of Break A Pull Speed 0.20 in./min Area 0.0245 sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)*	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)*	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)*	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0				
811	0.85	24	25	847	0.94	27	25	1,060	1.05	30	25				
1,380	1.85	53	50	1,450	2.00	57	50	1,550	1.87	53	50				
1,910	2.70	77	75	1,780	2.82	81	75	1,920	2.73	78	75				
2,110	3.41	97	100	2,140	3.60	103	100	2,370	3.68	105	100				
2,470	4.44	127	125	2,380	4.52	129	125	2,530	4.51	129	125				
2,760	5.45	156	150	2,740	5.42	155	150	2,730	5.40	154	150				
2,960	6.81	195	200	2,780	6.21	177	175	2,850	6.16	176	175				
2,920	7.34	210	215	2,910	7.02	201	200	2,980	6.40	183	179				
				3,110	7.58	217	210								

*No extensometer used. Amount of extension was measured with dividers for a 2-in. gage.

Table B-6 (cont'd)

Radiation-Cryotemperature Test Data: Geon 8800 (Material H)

Type of Test Ambient-air Low Dose

Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 3,170/313 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 171 %
Extensometer (2.0-in. gage length) 176 %
Crosshead Pull Speed 0.20 in./min
Date of Tensile Test 9-30-63

Radiation Exposure:
Gamma 4.2(9) ergs/gm(C)
Neutron (E < 0.48 ev) 5.1(13) n/cm2
Neutron (E > 2.9 Mev) 5.8(14) n/cm2

Date of Irradiation 9-13-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break A Pull Speed 0.20 in./min Area 0.0284 sq in.				Quality of Break A Pull Speed 0.20 in./min Area 0.0303 sq in.				Quality of Break A Pull Speed 0.20 in./min Area 0.0270 sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)*	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)*	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)*	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0				
1,060	0.81	23	25	958	0.79	23	25	963	0.84	24	25				
1,620	1.63	47	50	1,520	1.75	50	50	1,480	1.66	47	50				
2,050	2.60	74	75	1,920	2.61	75	75	2,000	2.56	73	75				
2,500	3.51	100	100	2,280	3.40	97	100	2,300	3.46	99	100				
2,720	4.37	125	125	2,580	4.27	122	125	2,700	4.35	124	125				
2,930	5.16	147	150	2,840	5.16	147	150	2,850	5.11	146	150				
3,390	6.03	172	175	3,110	5.96	170	175	2,930	5.80	166	173				
3,460	6.24	178	180												

*No extensometer used. Amount of extension was measured with dividers for a 2-in. gage.

Table B-6 (cont'd)

Radiation-Cryotemperature Test Data: Geon 8800 (Material H)

Type of Test Ambient-air High Dose

Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 2,610/213 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 130 %
Extensometer (2.0-in. gage length) 130 %
Crosshead Pull Speed 0.20 in./min
Date of Tensile Test 9-30-63

Radiation Exposure:
Gamma 7.9(9) ergs/gm(C)
Neutron (E < 0.48 ev) 4.6(13) n/cm²
Neutron (E > 2.9 Mev) 2.5(14) n/cm²

Date of Irradiation 9-13-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break A Pull Speed 0.20 in./min Area 0.0335 sq in.				Quality of Break A Pull Speed 0.20 in./min Area 0.0315 sq in.				Quality of Break A Pull Speed 0.20 in./min Area 0.0319 sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)*	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)*	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)*	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0				
897	0.83	24	25	922	0.86	25	25	847	0.84	24	25				
1,400	1.73	49	50	1,460	1.76	50	50	1,540	1.82	52	50				
1,910	2.72	78	75	1,970	2.65	76	75	1,790	2.54	73	75				
2,240	3.69	105	100	2,290	3.58	102	100	2,320	3.52	101	100				
2,480	4.34	124	125	2,480	4.28	122	125	2,450	3.92	112	113				
2,810	5.15	147	147	2,580	4.55	130	130								

*No extensometer used. Amount of extension was measured with dividers for a 2-in. gage.

Table B-7

Radiation-Cryotemperature Test Data: Geon 8800 (Material H)

Type of Test LN2 Controls

Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 9,710/1,230 psi
Total Elongation (avg):
Pull Rod (3.5-in. gage length) 1.77 %
Pull Rod Speed at Break (avg) 0.007 in./min
Pull Assembly Unit East
Date of Tensile Test 8-2-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron(E < 0.48 ev) 0 n/cm²
Neutron(E > 2.9 Mev) 0 n/cm²

Date of Irradiation Not Applicable

Specimen 1			Specimen 2			Specimen 3		
Rod ___ Position ___			Rod 8 Position 2			Rod 8 Position 3		
Quality of Break ___			Quality of Break B			Quality of Break D		
Rod Speed ___ in./min			Rod Speed 0.003 in./min			Rod Speed 0.011 in./min		
Area ___ sq in.			Area 0.0332 sq in.			Area 0.0313 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
			0	0	0	0	0	0
			2,650	0.024	0.69	2,560	0.001	0.30
			9,950	0.055	1.56	5,590	0.029	0.83
			9,040	0.056	1.60	7,090	0.047	1.34
			8,890	0.056	1.60	7,920	0.052	1.49
			9,200	0.057	1.63	8,400	0.056	1.60
			9,410	0.057	1.63	8,720	0.059	1.69
			9,710	0.058	1.66	8,910	0.060	1.71
			9,950	0.058	1.66	9,010	0.061	1.74
			10,000	0.059	1.69			
			10,200	0.060	1.71			
			10,300	0.061	1.74			
			10,300	0.061	1.74			
			10,400	0.062	1.76			
			10,400	0.063	1.80			

*Based on pull-rod travel

Table B-7 (cont'd)

Radiation-Cryotemperature Test Data: Geon 8800 (Material H)

Type of Test LN$_2$ Low Dose

Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 8,340/X psi
Total Elongation (avg):
Pull Rod (4.0-in. gage length) 0.70 %
Pull Rod Speed at Break (avg) 0.023 in./min
Pull Assembly Unit East
Date of Tensile Test 9-10-63

Radiation Exposure:
Gamma 5.8(9) ergs/gm(C)
Neutron ($E < 0.48$ ev) 8.3(13) n/cm^2
Neutron ($E > 2.9$ Mev) 1.2(15) n/cm^2

Date of Irradiation 9-10-63

Specimen 1			Specimen 2			Specimen 3		
Rod 1 Position 2 Quality of Break C Rod Speed 0.023 in./min Area 0.0712 sq in.			Rod Position Quality of Break Rod Speed in./min Area sq in.			Rod Position Quality of Break Rod Speed in./min Area sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0						
154	0.002	0.05						
1,140	0.005	0.13						
1,780	0.007	0.18						
2,850	0.010	0.25						
4,000	0.014	0.35						
4,980	0.018	0.45						
6,130	0.022	0.55						
7,200	0.025	0.63						
8,340	0.028	0.70						

*Based on pull-rod travel

Table B-7 (cont'd)

Radiation-Cryotemperature Test Data: Geon 8800 (Material H)

Type of Test LN$_2$ Low Dose

Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 7,500/1,410 psi
Total Elongation (avg):
Pull Rod (4.0-in. gage length) 2.08 %
Pull Rod Speed at Break (avg) 0.020 in./min
Pull Assembly Unit East
Date of Tensile Test 9-10-63

Radiation Exposure:
Gamma 6.6(9) ergs/gm(C)
Neutron (E < 0.48 ev) 1.4(14) n/cm^2
Neutron (E > 2.9 Mev) 1.5(15) n/cm^2

Date of Irradiation 9-10-63

Specimen 1			Specimen 2			Specimen 3		
Rod 8 Position 1 Quality of Break C Rod Speed 0.022 in./min Area 0.0721 sq in.			Rod 8 Position 2 Quality of Break C Rod Speed 0.018 in./min Area 0.0706 sq in.			Rod Position Quality of Break Rod Speed in./min Area sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0			
1,030	0.006	0.15	71	0.009	0.23			
1,840	0.011	0.28	425	0.015	0.38			
2,540	0.016	0.40	779	0.021	0.53			
3,590	0.023	0.58	2,610	0.029	0.73			
4,540	0.030	0.75	1,700	0.035	0.88			
5,490	0.038	0.95	2,310	0.041	1.03			
6,410	0.044	1.10	3,140	0.049	1.23			
7,300	0.054	1.35	3,990	0.056	1.40			
8,290	0.063	1.58	4,960	0.064	1.60			
			5,810	0.091	2.28			
			6,700	0.103	2.58			

*Based on pull-rod travel

Table B-7 (cont'd)

Radiation-Cryotemperature Test Data: Geon 8800 (Material H)

Type of Test LN2 High Dose   Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 10,700/X psi
Total Elongation (avg):
Pull Rod (4.0-in. gage length) 1.95 %
Pull Rod Speed at Break (avg) 0.027 in./min
Pull Assembly Unit East
Date of Tensile Test 9-11-63

Radiation Exposure:
Gamma 1.4(10) ergs/gm(C)
Neutron($E < 0.48$ ev) 2.7(14) n/cm^2
Neutron($E > 2.9$ Mev) 3.2(15) n/cm^2

Date of Irradiation 9-11-63

Specimen 1			Specimen 2			Specimen 3		
Rod 7 Position 3 Quality of Break C Rod Speed 0.027 in./min Area 0.0687 sq in.			Rod ___ Position ___ Quality of Break ___ Rod Speed ___ in./min Area ___ sq in.			Rod ___ Position ___ Quality of Break ___ Rod Speed ___ in./min Area ___ sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0						
466	0.009	0.23						
1,380	0.014	0.35						
2,150	0.020	0.50						
2,940	0.024	0.60						
4,070	0.032	0.80						
5,090	0.039	0.98						
6,210	0.046	1.15						
7,280	0.055	1.38						
8,450	0.063	1.58						
9,470	0.070	1.75						
10,700	0.078	1.95						

*Based on pull-rod travel

Table B-7 (cont'd)

Radiation-Cryotemperature Test Data: Geon 8800 (Material H)

Type of Test LN2 High Dose

Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 7,530/1,760 psi
Total Elongation (avg):
Pull Rod (4.0-in. gage length) 1.73 %
Pull Rod Speed at Break (avg) 0.015 in./min
Pull Assembly Unit East
Date of Tensile Test 9-11-63

Radiation Exposure:
Gamma 1.3(10) ergs/gm(C)
Neutron(E < 0.48 ev) 2.7(14) n/cm^2
Neutron(E > 2.9 Mev) 3.0(15) n/cm^2

Date of Irradiation 9-11-63

Specimen 1			Specimen 2			Specimen 3		
Rod 8 Position 3 Quality of Break C Rod Speed 0.012 in./min Area 0.0694 sq in.			Rod 8 Position 4 Quality of Break C Rod Speed 0.018 in./min Area 0.0705 sq in.			Rod Position Quality of Break Rod Speed in./min Area sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0			
216	0.004	0.10	227	0.009	0.23			
360	0.006	0.15	468	0.013	0.33			
634	0.008	0.20	794	0.017	0.43			
893	0.011	0.28	1,130	0.020	0.50			
1,240	0.013	0.33	1,570	0.025	0.63			
1,610	0.015	0.38	2,140	0.030	0.75			
2,070	0.018	0.45	2,840	0.035	0.88			
2,580	0.021	0.53	3,530	0.041	1.03			
3,010	0.025	0.63	4,270	0.047	1.18			
3,660	0.029	0.73	5,100	0.055	1.38			
4,220	0.034	0.85	5,880	0.063	1.58			
4,930	0.038	0.95	6,810	0.072	1.80			
5,530	0.043	1.08	7,660	0.080	2.00			
6,530	0.049	1.23	8,520	0.089	2.23			

*Based on pull-rod travel

Table B-8 (Rejections)

Radiation-Cryotemperature Test Data: Geon 8800 (Material H)

Type of Test Tensile

Type of Material Electrical Insulation

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Ultimate Tensile Strength (psi)	Comments
Irradiated	Tested			Gamma [ergs/gm(C)]	Neutron (n/cm^2) $E < 0.48$ ev	Neutron (n/cm^2) $E > 2.9$ Mev		
	5-15-63	0-X-1 0-X-2 0-X-3 0-X-4	0.20 0.20 0.20 0.20	0	0	0	3,320 3,570 2,810 2,440 3,035/549	Aluminum doublers with large cross-sectional area.
				(Ambient-Air Controls)				
4-25-63	5-15-63	1-N-1 1-N-2 1-N-3	0.20 0.20 0.20	6.0(9)	4.9(13)	1.2(15)	2,370 2,450 2,170 2,330/165	Same as ambient-air controls.
				(Ambient-Air Low Dose)				
4-25-63	5-15-63	2-N-1 2-N-2 2-N-3	0.20 0.20 0.20	1.1(10)	1.2(14)	2.4(15)	1,740 2,070 1,890 1,900/195	Same as ambient-air controls.
				(Ambient-Air High Dose)				
	4-19-63	8-1-WX 8-2-WX 8-3-WX	No Values	0	0	0	No Values	All specimens broke but no data were obtained.
				(LN_2 Controls)				
	8-2-63	8-1-EX 10-4-EX	No Values	0	0	0	No Values	Same as LN_2 controls tested 4-19-63.
				(LN_2 Controls)				
4-25-63	4-25-63	8-1-WW 8-2-WW 8-3-WW	No Values	4.0(9)	7.7(14)	5.5(14)	No Values	Same as LN_2 controls tested 4-19-63.
				(LN_2 Low Dose)				

Table B-9

Radiation-Cryotemperature Test Data: Duroid 5600 (Material I)

Type of Test Ambient-Air Controls

Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 2,660/121 psi
Total Elongation (avg):
Crosshead (4.0-in. gage length) 1.35 %
Extensometer (2.0-in. gage length) 0.83 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 5-17-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron (E < 0.48 ev) 0 n/cm^2
Neutron (E > 2.9 Mev) 0 n/cm^2

Date of Irradiation Not Applicable

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0631 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0667 sq in.				Quality of Break A Pull Speed 0.05 in./min Area 0.0675 sq in.				Quality of Break A Pull Speed 0.05 in./min Area 0.0630 sq in.			
		Elongation				Elongation				Elongation				Elongation	
Tensile Stress (psi)	Crosshead Travel (in.)	Crosshead (%)	Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Crosshead (%)	Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Crosshead (%)	Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Crosshead (%)	Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
950	0.020	0.50	0.12	705	0.015	0.38	0.10	415	0.015	0.38	0.05	190	0.010	0.25	0.03
1,770	0.030	0.75	0.29	1,080	0.020	0.50	0.12	801	0.020	0.50	0.11	825	0.020	0.50	0.10
2,340	0.040	1.00	0.48	1,420	0.025	0.63	0.24	1,100	0.025	0.63	0.16	1,270	0.025	0.63	0.17
2,630	0.047	1.18	0.65	1,750	0.030	0.75	0.34	1,440	0.030	0.75	0.24	1,700	0.030	0.75	0.27
				2,070	0.035	0.88	0.46	1,750	0.035	0.88	0.32	2,050	0.035	0.88	0.38
				2,280	0.040	1.00	0.58	2,000	0.040	1.00	0.41	2,320	0.040	1.00	0.49
				2,430	0.045	1.13	0.69	2,280	0.045	1.13	0.53	2,510	0.045	1.13	0.60
				2,520	0.050	1.25	0.80	2,480	0.050	1.25	0.64	2,670	0.050	1.25	0.73
								2,650	0.055	1.38	0.77	2,730	0.055	1.38	0.89
								2,760	0.060	1.50	0.91				
								2,770	0.063	1.58	0.99				

Table B-9 (cont'd)

Radiation-Cryotemperature Test Data: Duroid 5600 (Material I)

Type of Test Ambient-Air Low Dose

Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 727/193 psi
Total Elongation (avg):
Crosshead (4.0-in. gage length) 0.95 %
Extensometer (2.0-in. gage length) 0.13 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 9-27-63

Radiation Exposure:
Gamma 7.8(9) ergs/gm(C)
Neutron (E < 0.48 ev) 3.9(13) n/cm²
Neutron (E > 2.9 Mev) 1.0(15) n/cm²

Date of Irradiation 9-13-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break A Pull Speed 0.05 in./min Area 0.0657 sq in.				Quality of Break A Pull Speed 0.05 in./min Area 0.0646 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0611 sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0				
183	0.010	0.25	0.03	108	0.010	0.25	0.02	98	0.010	0.25	0.02				
411	0.020	0.50	0.06	248	0.020	0.50	0.04	246	0.020	0.50	0.04				
701	0.030	0.75	0.11	495	0.030	0.75	0.08	442	0.030	0.75	0.07				
853	0.036	0.90	0.15	526	0.032	0.80	0.09	671	0.040	1.00	0.11				
								802	0.046	1.15	0.14				

Table B-9 (cont'd)

Radiation-Cryotemperature Test Data: Duroid 5600 (Material I)

Type of Test: Ambient-Air High Dose

Type of Material: Electrical Insulation

Ult. Tensile Strength (avg) 564/306 psi
Total Elongation (avg):
Crosshead (4.0-in. gage length) 0.92 %
Extensometer (2.0-in. gage length) 0.08 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 9-27-63

Radiation Exposure:
Gamma 1.2(10) ergs/gm(C)
Neutron (E < 0.48 ev) 2.9(13) n/cm^2
Neutron (E > 2.9 Mev) 2.0(15) n/cm^2

Date of Irradiation 9-13-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break ___ Pull Speed ___ in./min Area ___ sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0625 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0691 sq in.				Quality of Break ___ Pull Speed ___ in./min Area ___ sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
				0	0	0	0	0	0	0	0				
				96	0.010	0.25	0.02	101	0.010	0.25	0.02				
				288	0.020	0.50	0.04	202	0.020	0.50	0.03				
				592	0.030	0.75	0.08	318	0.030	0.75	0.05				
				736	0.037	0.93	0.10	391	0.036	0.90	0.06				

Table B-10

Radiation-Cryotemperature Test Data: Duroid 5600 (Material I)

Type of Test LN2 Controls Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 7,120/585 psi
Total Elongation (avg):
Pull Rod (4.0-in. gage length) 1.45 %
Pull Rod Speed at Break (avg) 0.035 in./min
Pull Assembly Unit East
Date of Tensile Test 8-2-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron (E < 0.48 ev) 0 n/cm^2
Neutron (E > 2.9 Mev) 0 n/cm^2
Date of Irradiation Not Applicable

Specimen 1			Specimen 2			Specimen 3		
Rod 9 Position 1 Quality of Break B Rod Speed 0.035 in./min Area 0.0629 sq in.			Rod 9 Position 2 Quality of Break B Rod Speed 0.034 in./min Area 0.0714 sq in.			Rod 9 Position 3 Quality of Break B Rod Speed 0.035 in./min Area 0.0676 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
970	0.008	0.20	882	0.009	0.23	918	0.010	0.25
1,890	0.013	0.33	1,550	0.013	0.33	1,640	0.014	0.35
2,830	0.017	0.43	2,210	0.018	0.45	2,340	0.019	0.48
3,700	0.022	0.55	3,100	0.023	0.58	3,140	0.024	0.60
4,640	0.029	0.73	3,950	0.031	0.78	4,070	0.031	0.78
5,660	0.037	0.93	4,900	0.039	0.98	5,000	0.039	0.98
6,770	0.047	1.18	5,780	0.048	1.20	6,000	0.050	1.25
7,730	0.055	1.38	6,740	0.058	1.45	6,880	0.061	1.53

*Based on pull-rod travel

Table B-10 (cont'd)

Radiation-Cryotemperature Test Data: Duroid 5600 (Material I)

Type of Test LN_2 Low Dose Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 7,140/744 psi
Total Elongation (avg):
Pull Rod (4.0 -in. gage length) 1.26 %
Pull Rod Speed at Break (avg) 0.025 in./min
Pull Assembly Unit West
Date of Tensile Test 4-25-63

Radiation Exposure:
Gamma 4.6(9) ergs/gm(C)
Neutron(E < 0.48 ev) 1.1(14) n/cm^2
Neutron(E > 2.9 Mev) 6.9(14) n/cm^2

Date of Irradiation 4-25-63

Specimen 1			Specimen 2			Specimen 3		
Rod 7 Position 1 Quality of Break B Rod Speed 0.026 in./min Area 0.0648 sq in.			Rod 7 Position 2 Quality of Break B Rod Speed 0.025 in./min Area 0.0628 sq in.			Rod 7 Position 3 Quality of Break B Rod Speed 0.025 in./min Area 0.0643 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
309	0.006	0.15	1,040	0.007	0.18	1,400	0.008	0.20
1,420	0.011	0.28	2,260	0.013	0.33	2,600	0.013	0.33
3,400	0.020	0.50	3,740	0.022	0.55	4,000	0.024	0.60
5,250	0.032	0.80	5,340	0.034	0.85	5,370	0.033	0.83
6,790	0.045	1.13	6,770	0.047	1.18	6,690	0.049	1.23
7,950	0.055	1.38						

*Based on pull-rod travel

Table B-10 (cont'd)

Radiation-Cryotemperature Test Data: Duroid 5600 (Material I)

Type of Test LN2 Low Dose

Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 6,660/325 psi
Total Elongation (avg):
Pull Rod (4.0-in. gage length) 1.44 %
Pull Rod Speed at Break (avg) 0.031 in./min
Pull Assembly Unit East
Date of Tensile Test 9-11-63

Radiation Exposure:
Gamma 6.9(9) ergs/gm(C)
Neutron($E < 0.48$ ev) 1.4(14) n/cm^2
Neutron($E > 2.9$ Mev) 1.4(15) n/cm^2

Date of Irradiation 9-11-63

Specimen 1			Specimen 2			Specimen 3		
Rod 9 Position 1 Quality of Break B Rod Speed 0.029 in./min Area 0.0630 sq in.			Rod 9 Position 2 Quality of Break B Rod Speed 0.034 in./min Area 0.0616 sq in.			Rod 9 Position 3 Quality of Break B Rod Speed 0.031 in./min Area 0.0627 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
698	0.005	0.13	471	0.008	0.20	781	0.009	0.23
1,460	0.011	0.28	1,010	0.012	0.30	1,400	0.012	0.30
2,100	0.016	0.40	1,830	0.018	0.45	3,160	0.017	0.43
3,080	0.022	0.55	2,740	0.024	0.60	3,350	0.023	0.58
4,140	0.030	0.75	3,880	0.031	0.78	4,310	0.031	0.78
4,980	0.039	0.98	4,900	0.040	1.00	5,410	0.039	0.98
5,790	0.047	1.18	5,440	0.050	1.25	6,170	0.048	1.20
6,540	0.056	1.40	6,450	0.059	1.48	7,000	0.057	1.43

*Based on pull-rod travel

Table B-10 (cont'd)

Radiation-Cryotemperature Test Data: Duroid 5600 (Material I)

Type of Test LN_2 High Dose   Type of Material Electrical Insulation

Ult. Tensile Strength (avg) 5,800/402 psi
Total Elongation (avg):
Pull Rod (4.0 -in. gage length) 1.15 %
Pull Rod Speed at Break (avg) 0.027 in./min
Pull Assembly Unit East
Date of Tensile Test 9-11-63

Radiation Exposure:
Gamma 1.4(10) ergs/gm(C)
Neutron(E < 0.48 ev) 2.9(14) n/cm²
Neutron(E > 2.9 Mev) 2.9(15) n/cm²
Date of Irradiation 9-11-63

Specimen 1			Specimen 2			Specimen 3		
Rod 9 Position 4 Quality of Break A Rod Speed 0.028 in./min Area 0.0606 sq in.			Rod 9 Position 5 Quality of Break A Rod Speed 0.027 in./min Area 0.0599 sq in.			Rod 9 Position 6 Quality of Break B Rod Speed 0.025 in./min Area 0.0618 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
825	0.006	0.15	535	0.006	0.15	275	0.006	0.15
1,450	0.011	0.28	1,020	0.009	0.23	501	0.009	0.23
2,060	0.016	0.40	1,490	0.012	0.30	841	0.012	0.30
2,720	0.020	0.50	2,020	0.016	0.40	1,150	0.016	0.40
3,380	0.025	0.63	2,640	0.019	0.48	1,570	0.019	0.48
3,960	0.031	0.78	3,210	0.022	0.55	1,960	0.023	0.58
4,490	0.035	0.88	3,910	0.026	0.65	2,430	0.026	0.65
5,200	0.040	1.00	4,510	0.031	0.78	2,880	0.028	0.70
5,690	0.046	1.15	5,050	0.036	0.90	3,400	0.031	0.78
			5,660	0.041	1.03	3,960	0.034	0.85
			6,200	0.047	1.18	4,430	0.036	0.90
						5,000	0.042	1.05
						5,520	0.045	1.13

*Based on pull-rod travel

Table B-11 (Rejections)

Radiation-Cryotemperature Test Data: Duroid 5600 (Material I)

Type of Test Tensile Type of Material Electrical Insulation

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Ultimate Tensile Strength (psi)	Comments
				Gamma [ergs/gm(C)]	Neutron (n/cm^2)			
Irradiated	Tested				$E < 0.48$ ev	$E > 2.9$ Mev		
4-25-63	5-17-63	1-N1-1 1-N1-2 1-N1-3	(See comments) 0.05 0.05	6.0(9)	4.1(13) (Ambient Low Dose)	1.3(15)	X 1,050 1,110 1,080/53	First specimen was broken in handling. No extensometer correlation possible with pull-rod movement on second and third specimens.
4-25-63	5-17-63	2-N1-1 2-N1-2 2-N1-3	No Values	1.1(10)	1.2(14) (Ambient High Dose)	2.3(15)	No Values	All three specimens were broken in removing from rack following irradiation.
9-13-63	9-27-63	1-E3-1	No Value	1.2(10)	2.9(13) (Ambient High Dose)	2.0(15)	No Value	Specimen broken in removing from rack following irradiation.
	4-19-63	7-1-WW 7-2-WW 7-3-WW	0.016 0.032 0.025	0	0 (LN_2 Controls)	0	5,310 5,180 7,170 5,890/1,180	Data rejected. Pull speed used was variable on first specimen. Second and third specimens were pulled at a slow rate. Rerun produced data which are more uniform and also more representative.

Table B-12

Radiation-Cryotemperature Test Data: Lamicoid 6038E (Material J)

Type of Test Ambient-Air Controls

Type of Material Electrical Laminate

Ult. Tensile Strength (avg) 56,500/3,300 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 3.62 %
Extensometer (2.0-in. gage length) 2.00 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 6-24-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron ($E < 0.48$ ev) 0 n/cm^2
Neutron ($E > 2.9$ Mev) 0 n/cm^2

Date of Irradiation Not Applicable

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break A Pull Speed 0.05 in./min Area 0.0319 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0325 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0317 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0313 sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,980	0.010	0.29	0.04	2,770	0.010	0.29	0.05	1,260	0.010	0.29	0.02	2,820	0.010	0.29	0.04
6,900	0.020	0.57	0.12	6,770	0.020	0.57	0.14	5,040	0.020	0.57	0.09	7,360	0.020	0.57	0.12
13,200	0.030	0.86	0.23	11,400	0.030	0.86	0.23	10,100	0.030	0.86	0.20	12,800	0.030	0.86	0.22
18,500	0.040	1.14	0.31	16,000	0.040	1.14	0.36	15,400	0.040	1.14	0.34	18,100	0.040	1.14	0.35
23,200	0.050	1.43	0.55	21,000	0.050	1.43	0.53	20,500	0.050	1.43	0.50	23,000	0.050	1.43	0.56
27,900	0.060	1.71	0.72	25,500	0.060	1.71	0.70	25,200	0.060	1.71	0.67	27,500	0.060	1.71	0.76
32,300	0.070	2.00	0.89	30,300	0.070	2.00	0.87	29,900	0.070	2.00	0.85	32,200	0.070	2.00	0.97
37,300	0.080	2.29	1.09	35,200	0.080	2.29	1.04	34,300	0.080	2.29	1.03	36,200	0.080	2.29	1.16
41,700	0.090	2.57	1.28	40,000	0.090	2.57	1.22	38,900	0.090	2.57	1.22	40,500	0.090	2.57	1.37
46,000	0.100	2.86	1.46	44,600	0.100	2.86	1.41	43,500	0.100	2.86	1.42	44,800	0.100	2.86	1.56
50,200	0.110	3.14	1.64	48,900	0.110	3.14	1.59	47,400	0.110	3.14	1.58	49,300	0.110	3.14	1.77
54,700	0.120	3.43	1.85	52,300	0.117	3.34	1.74	51,800	0.120	3.43	1.78	54,400	0.120	3.43	1.99
59,100	0.130	3.71	2.08					55,900	0.130	3.71	1.96	58,700	0.130	3.71	2.20

Table B-12 (cont'd)

Radiation-Cryotemperature Test Data: Lamicoid 6038E (Material J)

Type of Test: Ambient-Air Low Dose

Type of Material: Electrical Laminate

Ult. Tensile Strength (avg) 56,400/355 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 4.03 %
Extensometer (2.0-in. gage length) 2.07 %
Crosshead Pull Speed 0.28 in./min
Date of Tensile Test 5-17-63

Radiation Exposure:
Gamma 1.1(10) ergs/gm(C)
Neutron (E < 0.48 ev) 1.2(14) n/cm^2
Neutron (E > 2.9 Mev) 2.2(15) n/cm^2

Date of Irradiation 4-25-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break A Pull Speed 0.50 in./min Area 0.0340 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0326 sq in.				Quality of Break Pull Speed in./min Area sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0								
22,900	0.060	1.71	0.68	7,050	0.025	0.71	0.08								
38,800	0.100	2.86	1.37	19,300	0.050	1.43	0.37								
50,800	0.130	3.71	1.92	30,600	0.075	2.14	0.79								
56,600	0.146	4.17	2.17	41,100	0.100	2.86	1.26								
				49,900	0.120	3.43	1.66								
				54,200	0.130	3.71	1.87								
				56,200	0.136	3.89	1.97								

Table B-12 (cont'd)

Radiation-Cryotemperature Test Data: Lamicoid 6038E (Material J)

Type of Test: Ambient-Air Low Dose

Type of Material: Electrical Laminate

Ult. Tensile Strength (avg) 57,300/X psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 3.71 %
Extensometer (2.0-in. gage length) 1.77 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 6-24-63

Radiation Exposure:
Gamma 1.1(10) ergs/gm(C)
Neutron (E < 0.48 ev) 1.9(14) n/cm^2
Neutron (E > 2.9 Mev) 2.4(15) n/cm^2

Date of Irradiation 5-29-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break A Pull Speed 0.05 in./min Area 0.0309 sq in.				Quality of Break Pull Speed in./min Area sq in.				Quality of Break Pull Speed in./min Area sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0												
1,130	0.010	0.29	0.01												
4,860	0.020	0.57	0.06												
10,400	0.030	0.86	0.14												
15,500	0.040	1.14	0.26												
21,100	0.050	1.43	0.42												
25,600	0.060	1.71	0.57												
30,300	0.070	2.00	0.72												
35,100	0.080	2.29	0.90												
39,700	0.090	2.57	1.07												
44,700	0.100	2.86	1.27												
49,100	0.110	3.14	1.44												
53,300	0.120	3.43	1.61												
57,300	0.130	3.71	1.77												

Table B-12 (cont'd)

Radiation-Cryotemperature Test Data: Lamicoid 6038E (Material J)

Type of Test Ambient-Air High Dose

Type of Material Electrical Laminate

Ult. Tensile Strength (avg) 57,100/1,000 psi
Total Elongation (avg):
Crosshead (3.5 -in. gage length) 3.92 %
Extensometer (2.0-in. gage length) 1.79 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 5-17-63

Radiation Exposure:
Gamma 5.8(10) ergs/gm(C)
Neutron (E < 0.48 ev) 5.5(14) n/cm^2
Neutron (E > 2.9 Mev) 3.1(16) n/cm^2

Date of Irradiation 4-25-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0326 sq in.				Quality of Break A Pull Speed 0.05 in./min Area 0.0334 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0324 sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0				
2,760	0.010	0.29	0.06	748	0.005	0.14	0.03	626	0.005	0.14	0.03				
7,050	0.020	0.57	0.11	4,640	0.015	0.43	0.08	4,320	0.015	0.43	0.08				
16,900	0.040	1.14	0.27	13,800	0.035	1.00	0.26	15,100	0.040	1.14	0.25				
26,400	0.060	1.71	0.52	23,300	0.055	1.57	0.54	24,700	0.060	1.71	0.55				
35,800	0.080	2.29	0.82	31,700	0.075	2.14	0.83	34,300	0.080	2.29	0.87				
43,800	0.100	2.86	1.13	39,800	0.095	2.71	1.12	42,900	0.100	2.86	1.21				
51,800	0.120	3.43	1.44	47,000	0.115	3.29	1.43	51,900	0.120	3.43	1.60				
56,200	0.131	3.74	1.62	54,300	0.135	3.86	1.74	57,900	0.136	3.89	1.87				
				57,200	0.145	4.14	1.88								

Table B-13

Radiation-Cryotemperature Test Data: Lamicoid 6038E (Material J)

Type of Test LN2 Controls | Type of Material Electrical Laminate

Ult. Tensile Strength (avg) 106,000/5,460 psi
Total Elongation (avg):
Pull Rod (3.5-in. gage length) 8.84 %
Pull Rod Speed at Break (avg) 0.028 in./min
Pull Assembly Unit West
Date of Tensile Test 4-19-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron(E < 0.48 ev) 0 n/cm^2
Neutron(E > 2.9 Mev) 0 n/cm^2

Date of Irradiation Not Applicable

Specimen 1			Specimen 2			Specimen 3		
Rod 1 Position 1 Quality of Break A Rod Speed 0.013 in./min Area 0.0335 sq in.			Rod 1 Position 2 Quality of Break A Rod Speed 0.025 in./min Area 0.0335 sq in.			Rod 1 Position 3 Quality of Break A Rod Speed 0.045 in./min Area 0.0335 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
1,190	0.004	0.12	596	0.006	0.16	1,040	0.001	0.01
3,280	0.008	0.22	2,680	0.011	0.30	2,090	0.002	0.02
5,810	0.012	0.34	4,170	0.013	0.37	3,130	0.003	0.04
20,400	0.042	1.20	16,800	0.034	0.96	7,450	0.008	0.22
35,800	0.058	1.95	34,000	0.069	1.97	14,500	0.019	0.55
47,700	0.098	2.81	42,900	0.087	2.48	23,900	0.038	1.09
58,300	0.123	3.52	50,400	0.116	3.31	45,500	0.081	2.30
60,500	0.129	3.69	60,100	0.147	4.20	63,500	0.128	3.65
75,300	0.168	4.80	66,800	0.156	4.46	61,100	0.134	3.83
73,300	0.171	4.89	75,100	0.190	5.44	72,300	0.167	4.76
83,500	0.217	6.21	71,600	0.193	5.53	81,100	0.202	5.77
91,400	0.241	6.87	84,100	0.220	6.28	98,200	0.277	7.90
97,600	0.269	7.68	90,900	0.252	7.20	105,000	0.309	8.82
101,000	0.278	7.95	96,900	0.274	7.83	109,000	0.338	9.65
105,000	0.295	8.41	102,000	0.285	8.14	112,000	0.349	9.96

*Based on pull-rod travel

NOTE: All these specimens delaminated badly.

Table B-13 (cont'd)

Radiation-Cryotemperature Test Data: Lamicoid 6038E (Material J)

Type of Test LN2 Low Dose — Type of Material Electrical Laminate

Ult. Tensile Strength (avg) 106,000/990 psi
Total Elongation (avg):
Pull Rod (3.5-in. gage length) 8.80 %
Pull Rod Speed at Break (avg) 0.017 in./min
Pull Assembly Unit West
Date of Tensile Test 4-25-63

Radiation Exposure:
Gamma 9.0(9) ergs/gm(C)
Neutron (E < 0.48 ev) 2.9(14) n/cm^2
Neutron (E > 2.9 Mev) 1.5(15) n/cm^2
Date of Irradiation 4-25-63

Specimen 1			Specimen 2			Specimen 3		
Rod 1 Position 1 Quality of Break A Rod Speed 0.013 in./min Area 0.0329 sq in.			Rod 1 Position 2 Quality of Break A Rod Speed 0.018 in./min Area 0.0329 sq in.			Rod 1 Position 3 Quality of Break A Rod Speed 0.019 in./min Area 0.0329 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
4,260	0.005	0.15	5,170	0.005	0.14	7,450	0.006	0.18
31,900	0.057	1.62	22,200	0.031	0.89	32,200	0.058	1.65
49,200	0.093	2.66	31,300	0.054	1.53	53,000	0.103	2.94
59,900	0.125	3.57	43,500	0.082	2.35	70,700	0.148	4.23
68,200	0.150	4.28	54,000	0.100	2.85	65,300	0.154	4.41
77,800	0.171	4.90	51,800	0.100	2.85	77,800	0.183	5.24
79,300	0.178	5.07	65,300	0.138	3.95	77,100	0.183	5.24
87,200	0.210	6.01	75,400	0.164	4.69	86,200	0.215	6.15
85,900	0.210	6.01	74,200	0.164	4.69	92,200	0.244	6.98
90,700	0.230	6.58	78,400	0.182	5.20	91,500	0.244	6.98
96,800	0.254	7.25	89,700	0.232	6.61	98,300	0.271	7.75
101,000	0.280	8.01	97,300	0.262	7.49	102,000	0.286	8.17
99,800	0.280	8.01	103,000	0.286	8.17	104,000	0.294	8.40
104,000	0.287	8.19	106,000	0.302	8.63	102,000	0.294	8.40
106,000	0.300	8.56	107,000	0.315	9.00	106,000	0.310	8.85

*Based on pull-rod travel

NOTE: All these specimens delaminated badly.

Table B-13 (cont'd)

Radiation-Cryotemperature Test Data: Lamicoid 6038E (Material J)

Type of Test LN2 High Dose — Type of Material Electrical Laminate

Ult. Tensile Strength (avg) 105,000/5,710 psi
Total Elongation (avg):
Pull Rod (3.5 -in. gage length) 7.87 %
Pull Rod Speed at Break (avg) 0.018 in./min
Pull Assembly Unit East
Date of Tensile Test 9-13-63

Radiation Exposure:
Gamma 6.7(10) ergs/gm(C)
Neutron (E < 0.48 ev) 8.5(14) n/cm^2
Neutron (E > 2.9 Mev) 1.3(16) n/cm^2
Date of Irradiation 9-13-63

Specimen 1			Specimen 2			Specimen 3		
Rod 2 Position 1 Quality of Break A Rod Speed 0.015 in./min Area 0.0308 sq in.			Rod 2 Position 2 Quality of Break A Rod Speed 0.026 in./min Area 0.0325 sq in.			Rod 2 Position 3 Quality of Break A Rod Speed 0.013 in./min Area 0.0332 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
5,270	0.008	0.23	3,080	0.002	0.05	9,960	0.009	0.27
21,000	0.034	0.97	16,900	0.011	0.32	37,300	0.044	1.27
35,100	0.059	1.68	31,400	0.037	1.05	51,300	0.080	2.29
51,700	0.088	2.52	46,100	0.068	1.93	62,400	0.114	3.27
64,400	0.113	3.23	55,700	0.089	2.55	78,000	0.160	4.57
73,300	0.131	3.75	68,000	0.114	3.27	83,100	0.174	4.97
77,100	0.137	3.92	77,700	0.140	4.01	72,500	0.174	4.97
80,000	0.148	4.23	85,700	0.168	4.79	82,800	0.177	5.05
95,600	0.194	5.53	82,000	0.171	4.88	88,200	0.198	5.67
102,000	0.217	6.19	83,800	0.174	4.97	81,400	0.207	5.93
100,000	0.218	6.23	84,000	0.175	5.01	87,800	0.224	6.41
93,300	0.219	6.26	83,000	0.177	5.05	90,500	0.234	6.69
88,100	0.220	6.28	88,300	0.192	5.49	89,000	0.234	6.69
105,000	0.243	6.94	98,400	0.249	7.10	98,000	0.267	7.63
111,000	0.273	7.80	101,000	0.259	7.41	103,000	0.294	8.40

*Based on pull-rod travel

NOTE: All these specimens delaminated badly.

Table B-14 (Rejections)

Radiation-Cryotemperature Test Data: Lamicoid 6038E (Material J)

Type of Test Tensile Type of Material Electrical Laminate

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Ultimate Tensile Strength (psi)	Comments
Irradiated	Tested			Gamma [ergs/gm(C)]	Neutron (n/cm^2) $E < 0.48$ ev	Neutron (n/cm^2) $E > 2.9$ Mev		
	5-17-63	0-X-1 0-X-2 0-X-3 0-X-4	0.05 0.05 0.05 0.05	0	0 (Ambient Controls)	0	65,600 57,600 55,900 54,000 58,300/5,630	No correlation possible between extensometer and rod movement. Values for ultimate tensile strength are o.k., but no stress-strain data available.
4-25-63	5-17-63	2-N1-1	(See comments)	1.1(10)	1.2(14) (Ambient Low Dose)	2.3(15)	No Value	No data available.

Table B-15

Radiation-Cryotemperature Test Data: CTL-91LD (Material K)

Type of Test Ambient-Air Controls

Type of Material Structural Laminate

Ult. Tensile Strength (avg) 29,300/1,750 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 2.30 %
Extensometer (2.0-in. gage length) 1.00 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 6-24-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron (E < 0.48 ev) 0 n/cm^2
Neutron (E > 2.9 Mev) 0 n/cm^2

Date of Irradiation Not Applicable

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0321 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0362 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0355 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0315 sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
934	0.007	0.20	0.01	1,660	0.010	0.29	0.04	1,130	0.010	0.29	0.02	2,540	0.012	0.34	0.04
4,820	0.020	0.57	0.09	3,730	0.015	0.43	0.09	3,950	0.015	0.43	0.08	6,670	0.023	0.66	0.12
8,710	0.030	0.86	0.19	5,520	0.020	0.57	0.14	7,900	0.025	0.71	0.20	10,800	0.033	0.94	0.22
13,100	0.040	1.14	0.34	9,390	0.030	0.86	0.27	12,100	0.035	1.00	0.35	15,200	0.045	1.29	0.37
17,700	0.050	1.43	0.50	13,500	0.040	1.14	0.42	15,800	0.045	1.29	0.50	19,700	0.055	1.57	0.53
21,800	0.060	1.71	0.66	17,500	0.050	1.43	0.59	19,700	0.055	1.57	0.66	23,800	0.065	1.86	0.69
25,800	0.070	2.00	0.81	21,300	0.060	1.71	0.75	23,400	0.065	1.86	0.82	27,900	0.075	2.14	0.86
30,300	0.080	2.29	0.98	25,100	0.070	2.00	0.91	26,700	0.073	2.09	0.95	31,000	0.079	2.26	0.98
				27,900	0.080	2.29	1.03								
				29,000	0.089	2.54	1.08								

Table B-15 (cont'd)

Radiation-Cryotemperature Test Data: CTL-91LD (Material K)

Type of Test Ambient-Air Low Dose

Type of Material Structural Laminate

Ult. Tensile Strength (avg) 32,700/2,070 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 2.44 %
Extensometer (2.0-in. gage length) 1.07 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 6-24-63

Radiation Exposure:
Gamma 1.1(10) ergs/gm(C)
Neutron (E < 0.48 ev) 1.9(14) n/cm²
Neutron (E > 2.9 Mev) 2.4(15) n/cm²
Date of Irradiation 5-29-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0312 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0306 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0309 sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0				
802	0.010	0.29	0.02	1,310	0.010	0.29	0.02	810	0.010	0.29	0.02				
3,850	0.020	0.57	0.09	4,080	0.020	0.57	0.09	3,890	0.020	0.57	0.08				
7,700	0.030	0.86	0.18	8,490	0.030	0.86	0.18	8,100	0.030	0.86	0.17				
12,200	0.040	1.14	0.31	13,100	0.040	1.14	0.32	13,000	0.040	1.14	0.32				
16,700	0.050	1.43	0.46	17,600	0.050	1.43	0.48	17,300	0.050	1.43	0.48				
21,000	0.060	1.71	0.61	21,900	0.060	1.71	0.65	21,100	0.060	1.71	0.62				
25,000	0.070	2.00	0.76	26,100	0.070	2.00	0.82	25,300	0.070	2.00	0.76				
29,500	0.080	2.29	0.92	30,700	0.080	2.29	1.05	29,300	0.080	2.29	0.93				
31,100	0.083	2.37	0.99	34,600	0.087	2.49	1.16	32,400	0.086	2.46	1.05				

Table B-15 (cont'd)

Radiation-Cryotemperature Test Data: CTL-91LD (Material K)

Type of Test: Ambient-Air High Dose

Type of Material: Structural Laminate

Ult. Tensile Strength (avg) 33,600/886 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 2.19 %
Extensometer (2.0-in. gage length) 1.09 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 6-24-63

Radiation Exposure:
Gamma 3.9(10) ergs/gm(C)
Neutron (E < 0.48 ev) 2.8(14) n/cm²
Neutron (E > 2.9 Mev) 6.4(15) n/cm²

Date of Irradiation 5-29-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0301 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0321 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0289 sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0				
2,990	0.010	0.29	0.06	3,110	0.010	0.29	0.06	2,420	0.010	0.29	0.05				
7,300	0.020	0.57	0.16	7,780	0.020	0.57	0.15	7,270	0.020	0.57	0.14				
12,300	0.030	0.86	0.31	12,500	0.030	0.86	0.26	11,800	0.030	0.86	0.24				
16,900	0.040	1.14	0.45	16,700	0.040	1.14	0.38	17,000	0.040	1.14	0.38				
21,900	0.050	1.43	0.60	21,000	0.050	1.43	0.53	21,800	0.050	1.43	0.53				
27,500	0.060	1.71	0.79	25,200	0.060	1.71	0.69	26,300	0.060	1.71	0.68				
31,700	0.070	2.00	0.98	29,600	0.070	2.00	0.88	30,500	0.070	2.00	1.08				
34,500	0.077	2.20	1.09	33,000	0.078	2.23	1.02	33,200	0.075	2.14	1.17				

Table B-16

Radiation-Cryotemperature Test Data: CTL-91LD (Material K)

Type of Test LN_2 Controls — Type of Material Structural Laminate

Ult. Tensile Strength (avg) 42,400/650 psi
Total Elongation (avg):
Pull Rod (3.5 -in. gage length) 3.17 %
Pull Rod Speed at Break (avg) 0.050 in./min
Pull Assembly Unit West
Date of Tensile Test 4-19-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron(E < 0.48 ev) 0 n/cm^2
Neutron(E > 2.9 Mev) 0 n/cm^2
Date of Irradiation Not Applicable

Specimen 1			Specimen 2			Specimen 3		
Rod 4 Position 1 Quality of Break B Rod Speed 0.056 in./min Area 0.0333 sq in.			Rod 4 Position 2 Quality of Break B Rod Speed 0.049 in./min Area 0.0316 sq in.			Rod 4 Position 3 Quality of Break B Rod Speed 0.045 in./min Area 0.0324 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
2,560	0.003	0.17	4,430	0.009	0.27	1,850	0.004	0.11
5,710	0.015	0.43	7,600	0.019	0.53	4,940	0.012	0.35
11,600	0.032	0.91	15,500	0.040	1.15	12,200	0.030	0.86
17,600	0.051	1.45	25,000	0.064	1.82	21,000	0.053	1.51
25,700	0.069	1.97	34,800	0.090	2.56	30,600	0.078	2.22
34,800	0.092	2.64	43,000	0.110	3.15	37,400	0.096	2.75
41,900	0.112	3.20				42,300	0.110	3.15

*Based on pull-rod travel

Table B-16 (cont'd)

Radiation-Cryotemperature Test Data: CTL-91LD (Material K)

Type of Test LN2 Low Dose

Type of Material Structural Laminate

Ult. Tensile Strength (avg) 41,700/0 psi
Total Elongation (avg):
Pull Rod (3.5-in. gage length) 3.27 %
Pull Rod Speed at Break (avg) 0.008 in./min
Pull Assembly Unit West
Date of Tensile Test 4-25-63

Radiation Exposure:
Gamma 9.3(9) ergs/gm(C)
Neutron(E < 0.48 ev) 2.1(14) n/cm²
Neutron(E > 2.9 Mev) 1.2(15) n/cm²

Date of Irradiation 4-25-63

Specimen 1			Specimen 2			Specimen 3		
Rod ___ Position ___ Quality of Break ___ Rod Speed ___ in./min Area ___ sq in.			Rod 4 Position 2 Quality of Break B Rod Speed 0.009 in./min Area 0.0324 sq in.			Rod 4 Position 3 Quality of Break B Rod Speed 0.006 in./min Area 0.0324 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
			0	0	0	0	0	0
			6,640	0.020	0.57	6,950	0.021	0.60
			11,100	0.032	0.91	16,700	0.045	1.29
			17,900	0.050	1.43	23,800	0.063	1.80
			25,500	0.067	1.91	30,300	0.079	2.26
			33,000	0.084	2.40	36,100	0.095	2.71
			38,600	0.097	2.77	40,100	0.107	3.06
			41,700	0.117	3.34	41,700	0.112	3.20

*Based on pull-rod travel

Table B-16 (cont'd)

Radiation-Cryotemperature Test Data: CTL-91LD (Material K)

Type of Test LN2 High Dose   Type of Material Structural Laminate

Ult. Tensile Strength (avg) 33,600/3,190 psi
Total Elongation (avg):
Pull Rod (3.5-in. gage length) 1.75 %
Pull Rod Speed at Break (avg) 0.027 in./min
Pull Assembly Unit East
Date of Tensile Test 9-13-63

Radiation Exposure:
Gamma 6.7(10) ergs/gm(C)
Neutron(E < 0.48 ev) 8.0(14) n/cm^2
Neutron(E > 2.9 Mev) 1.2(16) n/cm^2

Date of Irradiation 9-13-63

Specimen 1			Specimen 2			Specimen 3		
Rod 4 Position 2 Quality of Break A Rod Speed 0.029 in./min Area 0.0298 sq in.			Rod 4 Position 4 Quality of Break B Rod Speed 0.028 in./min Area 0.0290 sq in.			Rod 4 Position 6 Quality of Break B Rod Speed 0.024 in./min Area 0.0342 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
4,360	0.008	0.23	1,720	0.003	0.08	1,460	0.003	0.07
7,220	0.013	0.36	5,860	0.010	0.27	5,270	0.010	0.29
8,900	0.016	0.45	10,000	0.017	0.47	9,080	0.018	0.51
13,100	0.024	0.68	14,100	0.023	0.67	12,900	0.025	0.72
17,600	0.032	0.91	18,300	0.030	0.86	16,700	0.033	0.93
21,800	0.040	1.14	22,400	0.037	1.05	20,500	0.040	1.14
26,200	0.048	1.37	26,600	0.043	1.24	24,300	0.047	1.33
31,400	0.058	1.64	29,000	0.049	1.40	28,100	0.053	1.52
34,900	0.064	1.82	31,400	0.052	1.48	31,900	0.061	1.73
36,800	0.067	1.92				32,600	0.065	1.84

*Based on pull-rod travel

Table B-17 (Rejections)

Radiation-Cryotemperature Test Data: CTL-91LD (Material K)

Type of Test Tensile Type of Material Structural Laminate

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Ultimate Tensile Strength (psi)	Comments
				Gamma [ergs/gm(C)]	Neutron (n/cm^2)			
Irradiated	Tested				$E < 0.48$ ev	$E > 2.9$ Mev		
	5-16-63	0-X-1 0-X-2 0-X-3 0-X-4	0.05 0.05 0.05 0.05	0	0 (Ambient-Air Controls)	0	26,000 27,200 28,400 29,300 27,700/1,600	No correlation possible between extensometer and pull-rod movement. Ultimate strength data are o.k., but no stress-strain data are available. All specimens were rerun and are reported with the other data.
4-25-63	5-16-63	2-N1-1 2-N1-2 2-N1-3	0.05 0.05 0.05	1.1(10)	1.2(14) (Ambient-Air Low Dose)	2.3(15)	26,200 31,300 30,000 29,200/3,010	
4-25-63	5-16-63	3-N1-1 3-N1-2 3-N1-3	0.05 0.05 0.05	6.3(10)	2.7(14) (Ambient-Air High Dose)	3.2(16)	28,500 31,100 29,900 29,800/1,540	
4-25-63	4-25-63	4-1-WW	0.022	4.6(9)	1.1(14) (LN_2 Low Dose)	6.9(14)	42,200	No correlation possible between Instron x-head and pull-rod movement because of variable speed used in pulling.

Table B-18

Radiation-Cryotemperature Test Data: DC-2104 (Material L)

Type of Test: Ambient-Air Controls

Type of Material: Structural Laminate

Ult. Tensile Strength (avg) 16,000/971 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 1.91 %
Extensometer (2.0-in. gage length) 0.76 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 6-24-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron (E < 0.48 ev) 0 n/cm^2
Neutron (E > 2.9 Mev) 0 n/cm^2

Date of Irradiation: Not Applicable

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0439 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0435 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0386 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0410 sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
502	0.005	0.14	0.02	460	0.005	0.14	0.02	1,300	0.010	0.29	0.04	2,200	0.012	0.34	0.07
5,020	0.025	0.71	0.21	1,150	0.010	0.29	0.04	4,150	0.020	0.57	0.15	4,880	0.020	0.57	0.19
8,160	0.035	1.00	0.36	3,330	0.018	0.51	0.13	7,130	0.030	0.86	0.26	7,560	0.030	0.86	0.31
9,580	0.040	1.14	0.45	6,210	0.028	0.80	0.26	10,100	0.040	1.14	0.38	10,000	0.040	1.14	0.43
11,700	0.045	1.29	0.57	8,040	0.035	1.00	0.36	13,000	0.050	1.43	0.50	12,700	0.050	1.43	0.57
13,100	0.055	1.57	0.67	10,600	0.045	1.29	0.48	15,300	0.060	1.71	0.60	14,700	0.060	1.71	0.69
14,800	0.065	1.86	0.76	12,400	0.050	1.43	0.57					16,700	0.070	2.00	0.82
15,300	0.066	1.89	0.78	14,400	0.060	1.71	0.67					17,300	0.075	2.14	0.88
				16,400	0.067	1.91	0.79								

Table B-18 (cont'd)

Radiation-Cryotemperature Test Data: DC-2104 (Material L)

Type of Test Ambient-Air Low Dose

Type of Material Structural Laminate

Ult. Tensile Strength (avg) 19,300/1,420 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 2.20 %
Extensometer (2.0-in. gage length) 0.88 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 6-24-63

Radiation Exposure:
Gamma 1.1(10) ergs/gm(C)
Neutron (E < 0.48 ev) 1.9(14) n/cm²
Neutron (E > 2.9 Mev) 2.4(15) n/cm²

Date of Irradiation 5-29-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0385 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0428 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0413 sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation		Tensile Stress (psi)	Crosshead Travel (in.)	Elongation		Tensile Stress (psi)	Crosshead Travel (in.)	Elongation		Tensile Stress (psi)	Crosshead Travel (in.)	Elongation	
		Crosshead (%)	Extens (%)			Crosshead (%)	Extens (%)			Crosshead (%)	Extens (%)			Crosshead (%)	Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0				
1,560	0.007	0.20	0.04	935	0.005	0.14	0.04	2,910	0.010	0.29	0.09				
4,680	0.018	0.51	0.13	3,270	0.013	0.37	0.13	5,810	0.020	0.57	0.20				
7,670	0.027	0.77	0.24	7,480	0.025	0.71	0.30	8,960	0.030	0.86	0.34				
10,900	0.037	1.06	0.36	10,300	0.034	0.97	0.42	11,900	0.040	1.14	0.50				
13,800	0.047	1.34	0.48	11,900	0.042	1.20	0.50	14,400	0.050	1.43	0.64				
15,500	0.057	1.63	0.60	14,400	0.052	1.49	0.63	16,100	0.060	1.71	0.75				
17,000	0.067	1.91	0.64	16,500	0.062	1.77	0.75	18,200	0.070	2.00	0.88				
19,100	0.077	2.20	0.73	18,700	0.072	2.06	0.91	18,400	0.072	2.06	0.91				
20,800	0.087	2.49	0.83												

Table B-18 (cont'd)

Radiation-Cryotemperature Test Data: DC-2104 (Material L)

Type of Test Ambient-Air High Dose

Type of Material Structural Laminate

Ult. Tensile Strength (avg) 21,400/2,540 psi
Total Elongation (avg):
Crosshead (3.5-in. gage length) 2.41 %
Extensometer (2.0-in. gage length) 1.01 %
Crosshead Pull Speed 0.05 in./min
Date of Tensile Test 6-24-63

Radiation Exposure:
Gamma 3.9(10) ergs/gm(C)
Neutron (E < 0.48 ev) 2.8(14) n/cm^2
Neutron (E > 2.9 Mev) 6.4(15) n/cm^2

Date of Irradiation 5-29-63

Specimen 1				Specimen 2				Specimen 3				Specimen 4			
Quality of Break B Pull Speed 0.05 in./min Area 0.0387 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0395 sq in.				Quality of Break B Pull Speed 0.05 in./min Area 0.0368 sq in.				Quality of Break Pull Speed in./min Area sq in.			
Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)	Tensile Stress (psi)	Crosshead Travel (in.)	Elongation Crosshead (%)	Elongation Extens (%)
0	0	0	0	0	0	0	0	0	0	0	0				
520	0.003	0.09	0.01	760	0.004	0.11	0.02	2,450	0.010	0.29	0.09				
1,290	0.006	0.17	0.04	3,290	0.014	0.40	0.12	5,980	0.020	0.57	0.20				
4,140	0.015	0.43	0.15	5,950	0.024	0.69	0.25	8,700	0.030	0.86	0.32				
6,850	0.025	0.71	0.27	9,110	0.036	1.03	0.40	12,000	0.040	1.14	0.45				
9,700	0.035	1.00	0.41	11,900	0.046	1.31	0.55	14,900	0.050	1.43	0.59				
12,800	0.045	1.29	0.56	14,800	0.056	1.60	0.71	18,200	0.060	1.71	0.73				
15,400	0.055	1.57	0.70	17,200	0.066	1.89	0.85	20,400	0.070	2.00	0.84				
17,800	0.065	1.86	0.83	18,700	0.076	2.17	0.95	22,800	0.080	2.29	0.96				
19,500	0.075	2.14	0.94	19,200	0.079	2.26	0.98	23,500	0.084	2.40	0.99				
21,500	0.090	2.57	1.05												

Table B-19

Radiation-Cryotemperature Test Data: DC-2104 (Material L)

Type of Test LN2 Controls

Type of Material Structural Laminate

Ult. Tensile Strength (avg) 53,500/2,240 psi
Total Elongation (avg):
Pull Rod (3.5 -in. gage length) 5.41 %
Pull Rod Speed at Break (avg) 0.010 in./min
Pull Assembly Unit East
Date of Tensile Test 8-2-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron (E < 0.48 ev) 0 n/cm^2
Neutron (E > 2.9 Mev) 0 n/cm^2

Date of Irradiation Not Applicable

Specimen 1			Specimen 2			Specimen 3		
Rod 5 Position 1 Quality of Break A Rod Speed 0.009 in./min Area 0.0390 sq in.			Rod 5 Position 2 Quality of Break A Rod Speed 0.008 in./min Area 0.0389 sq in.			Rod 5 Position 3 Quality of Break A Rod Speed 0.012 in./min Area 0.0406 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
4,530	0.010	0.29	3,730	0.010	0.29	4,530	0.010	0.29
9,500	0.023	0.66	5,790	0.017	0.47	8,220	0.022	0.63
15,000	0.039	1.11	10,800	0.031	0.89	15,600	0.046	1.31
20,200	0.056	1.60	17,000	0.050	1.43	20,700	0.062	1.78
25,900	0.073	2.09	21,500	0.063	1.80	26,900	0.084	2.40
30,300	0.086	2.46	26,100	0.077	2.20	33,400	0.106	3.03
34,300	0.096	2.74	31,800	0.092	2.63	38,300	0.128	3.66
41,100	0.120	3.43	37,100	0.109	3.11	40,800	0.138	3.94
44,100	0.134	3.73	44,600	0.138	3.94	43,200	0.151	4.31
45,700	0.140	4.00	48,900	0.157	4.49	45,500	0.161	4.60
47,500	0.147	4.20	50,800	0.167	4.77	48,200	0.172	4.91
50,000	0.157	4.49	51,900	0.177	5.06	49,900	0.181	5.17
53,100	0.169	4.82				51,400	0.190	5.43
55,700	0.181	5.17				52,800	0.210	6.00

*Based on pull-rod travel

Table B-19 (cont'd)

Radiation-Cryotemperature Test Data: DC-2104 (Material L)

Type of Test: LN_2 Controls

Type of Material: Structural Laminate

Ult. Tensile Strength (avg) 50,600/X psi
Total Elongation (avg):
Pull Rod (3.5-in. gage length) 4.97 %
Pull Rod Speed at Break (avg) 0.039 in./min
Pull Assembly Unit West
Date of Tensile Test 4-19-63

Radiation Exposure:
Gamma 0 ergs/gm(C)
Neutron(E < 0.48 ev) 0 n/cm^2
Neutron(E > 2.9 Mev) 0 n/cm^2
Date of Irradiation Not Applicable

Specimen 1			Specimen 2			Specimen 3		
Rod 5 Position 1 Quality of Break B Rod Speed 0.039 in./min Area 0.0356 sq in.			Rod Position Quality of Break Rod Speed in./min Area sq in.			Rod Position Quality of Break Rod Speed in./min Area sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0						
5,620	0.016	0.46						
12,100	0.033	0.94						
18,800	0.053	1.51						
27,200	0.078	2.23						
34,300	0.104	2.97						
40,200	0.127	3.63						
44,900	0.146	4.17						
47,800	0.163	4.66						
50,600	0.174	4.97						

*Based on pull-rod travel

Table B-19 (cont'd)

Radiation-Cryotemperature Test Data: DC-2104 (Material L)

Type of Test LN2 Low Dose | Type of Material Structural Laminate

Ult. Tensile Strength (avg) 51,200/2,240 psi
Total Elongation (avg):
Pull Rod (3.5 -in. gage length) 5.67 %
Pull Rod Speed at Break (avg) 0.093 in./min
Pull Assembly Unit West
Date of Tensile Test 4-25-63

Radiation Exposure:
Gamma 6.5(9) ergs/gm(C)
Neutron(E < 0.48 ev) 1.4(14) n/cm^2
Neutron(E > 2.9 Mev) 8.5(14) n/cm^2

Date of Irradiation 4-25-63

Specimen 1			Specimen 2			Specimen 3		
Rod 5 Position 1 Quality of Break A Rod Speed 0.209 in./min Area 0.0366 sq in.			Rod 5 Position 2 Quality of Break B Rod Speed 0.031 in./min Area 0.0399 sq in.			Rod 5 Position 3 Quality of Break A Rod Speed 0.039 in./min Area 0.0392 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
1,640	0.005	0.14	1,380	0.006	0.16	1,870	0.007	0.19
3,140	0.012	0.34	3,010	0.010	0.28	3,330	0.011	0.30
9,700	0.028	0.80	6,640	0.019	0.53	10,100	0.031	0.89
20,400	0.065	1.85	14,300	0.040	1.15	17,300	0.057	1.63
26,600	0.086	2.45	21,500	0.067	1.91	24,900	0.083	2.37
35,100	0.120	3.42	28,000	0.092	2.62	31,800	0.109	3.12
44,400	0.159	4.53	33,100	0.117	3.33	38,400	0.136	3.87
53,100	0.205	5.86	39,600	0.145	4.13	43,700	0.159	4.53
			43,300	0.160	4.57	48,000	0.179	5.11
			47,300	0.178	5.08	51,300	0.205	5.85
			49,300	0.186	5.30			

*Based on pull-rod travel

NOTE: All these specimens delaminated badly.

Table B-21 (cont'd)

Radiation-Cryotemperature Test Data: Teflon TFE-7 (Material Q)

Type of Test LN2 Low Dose

Type of Material Dielectric Material

Ult. Tensile Strength (avg) 7990/505 psi
Total Elongation (avg):
Pull Rod (4.0 -in. gage length) 2.22 %
Pull Rod Speed at Break (avg) 0.026 in./min
Pull Assembly Unit East
Date of Tensile Test 9-10-63

Radiation Exposure:
Gamma 1.1(8) ergs/gm(C)
Neutron(E < 0.48 ev) 1.4(12) n/cm^2
Neutron(E > 2.9 Mev) 2.1(13) n/cm^2

Date of Irradiation 9-10-63

Specimen 1			Specimen 2			Specimen 3		
Rod 5 Position 1 Quality of Break B Rod Speed — in./min Area C.0616 sq in.			Rod 5 Position 2 Quality of Break B Rod Speed 0.025 in./min Area 0.0624 sq in.			Rod 5 Position 3 Quality of Break B Rod Speed 0.026 in./min Area 0.0629 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
	*		0	0	0	0	0	0
			321	0.006	0.15	795	0.012	0.30
			1,120	0.017	0.43	2,540	0.024	0.60
			2,570	0.026	0.65	4,060	0.034	0.85
			3,850	0.036	0.90	5,410	0.043	1.08
			4,970	0.045	1.13	6,360	0.052	1.30
			5,690	0.054	1.35	7,320	0.062	1.55
			6,730	0.063	1.58	7,950	0.073	1.83
			7,130	0.074	1.85	8,270	0.084	2.10
			7,460	0.083	2.08			
			7,700	0.093	2.33			

*Based on pull-rod travel

*Ice formation on rod ruined data on this specimen.

Table B-21 (cont'd)

Radiation-Cryotemperature Test Data: Teflon TFE-7 (Material Q)

Type of Test LN$_2$ High Dose | Type of Material Dielectric Material

Ult. Tensile Strength (avg) 8,690/266 psi
Total Elongation (avg):
Pull Rod (4.0 -in. gage length) 2.15 %
Pull Rod Speed at Break (avg) 0.036 in./min
Pull Assembly Unit East
Date of Tensile Test 9-10-63

Radiation Exposure:
Gamma 1.1(9) ergs/gm(C)
Neutron(E < 0.48 ev) 1.4(13) n/cm^2
Neutron(E > 2.9 Mev) 2.1(14) n/cm^2
Date of Irradiation 9-10-63

Specimen 1			Specimen 2			Specimen 3		
Rod 5 Position 4 Quality of Break C Rod Speed 0.037 in./min Area 0.0591 sq in.			Rod 5 Position 5 Quality of Break C Rod Speed 0.036 in./min Area 0.0591 sq in.			Rod 5 Position 6 Quality of Break D Rod Speed 0.034 in./min Area 0.0608 sq in.		
Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)	Tensile Stress (psi)	Pull-Rod Travel (in.)	*Elongation (%)
0	0	0	0	0	0	0	0	0
1,050	0.007	0.18	676	0.007	0.18	658	0.006	0.15
1,890	0.013	0.33	1,610	0.013	0.33	1,400	0.012	0.30
3,250	0.021	0.53	2,960	0.021	0.53	2,300	0.017	0.43
4,770	0.031	0.78	4,480	0.031	0.78	3,490	0.026	0.65
6,040	0.041	1.03	5,830	0.041	1.03	4,770	0.037	0.93
7,220	0.053	1.33	7,100	0.052	1.30	6,170	0.047	1.18
8,150	0.066	1.65	7,980	0.065	1.63	7,330	0.057	1.43
8,570	0.079	1.98	8,460	0.078	1.95	8,310	0.070	1.75
8,910	0.095	2.38				8,690	0.085	2.13

*Based on pull-rod travel

Table B-22

Radiation-Cryotemperature Test Data: Epon 828/Z (Material M)

Type of Test Potted-Wire Pull Out Type of Material Potting Compound

Date Irradiated	Date Tested	Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure: Gamma [ergs/gm(C)]	Radiation Exposure: Neutron (n/cm^2) $E < 0.48$ ev	Radiation Exposure: Neutron (n/cm^2) $E > 2.9$ Mev	Wire Pull Load (lb)	Comments
	5-14-63	0-X-1 0-X-2 0-X-3 0-X-4	0.20 0.20 0.20 0.20	0	0 (Ambient-air Controls)	0	40 37 37 37 38/1	All wires pulled out ok. Clean pulls - no compound on wires.
4-25-63	5-14-63	1-N1-1 1-N1-2 1-N1-3 1-N1-4	0.20 0.20 0.20 0.20	5.4(9)	5.9(13) (Ambient-air Low Dose)	1.0(15)	36 35 37 36 36/1	Same as ambient-air controls
4-25-63	5-14-63	2-N1-1 2-N1-2 2-N1-3 2-N1-4	0.20 0.20 0.20 0.20	1.1(10)	1.0(14) (Ambient-air High Dose)	2.2(15)	37 34 34 36 35/1	Same as ambient-air controls
	4-19-63	6-1-WX 6-2-WX 6-3-WX 6-4-WX	0.041 0.041 0.041 0.041	0	0 (LN_2 Controls)	0	44 32 43 38 39/9	Same as ambient-air controls
4-25-63	4-25-63	6-1-WW 6-2-WW 6-3-WW 6-4-WW	0.044 0.044 0.044 0.044	3.9(9)	1.3(14) (LN_2 Low Dose)	6.4(14)	65 55 75 61 64/10	Same as ambient-air controls
9-10-63	9-10-63	6-1-EN 6-2-EN 6-3-EN 6-4-EN	0.050 0.050 0.050 0.050	1.3(10)	2.1(14) (LN_2 High Dose)	2.8(15)	21 17 19 18 19/2	Same as ambient-air controls

Table B-23

Radiation-Cryotemperature Test Data: EC-2273B/A (Material N)

Type of Test Potted-Wire Pull Out   Type of Material Potting Compound

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Wire Pull Load (lb)	Comments
Irradiated	Tested			Gamma [ergs/gm(C)]	Neutron (n/cm^2) $E < 0.48$ ev	Neutron (n/cm^2) $E > 2.9$ Mev		
	5-14-63	0-X-1 0-X-2 0-X-3 0-X-4	0.20 0.20 0.20 0.20	0	0 (Ambient-air controls)	0	38 38 38 37 38/1	All wires broke. No wires pulled out. Some compound on all wires.
4-25-63	5-14-63	1-N1-1 1-N1-2 1-N1-3 1-N1-4	0.20 0.20 0.20 0.20	5.4(9)	5.9(13) (Ambient-air Low Dose)	1.0(15)	31 34 36 32 33/2	All wires pulled out ok. Some compound on all wires.
4-25-63	5-14-63	2-N1-1 2-N1-2 2-N1-3 2-N1-4	0.20 0.20 0.20 0.20	1.1(10)	1.0(14) (Ambient-air High Dose)	2.2(15)	21 19 31 30 25/6	Same as ambient-air low dose
4-25-63	4-25-63	10-1-WW 10-2-WW 10-3-WW 10-4-WW	0.086 0.086 0.086 0.086	3.5(9)	6.1(13) (LN_2 Low Dose)	4.2(14)	47 60 40 60 52/10	Same as ambient-air low dose

Table B-24 (Rejections)

Radiation-Cryotemperature Test Data: EC-2273B/A (Material N)

Type of Test Potted-Wire Pull Out Type of Material Potting Compound

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Wire Pull Load (lb)	Comments
				Gamma [ergs/gm(C)]	Neutron (n/cm^2)			
Irradiated	Tested				E < 0.48 ev	E > 2.9 Mev		
	4-19-63	10-1-WX 10-2-WX 10-3-WX 10-4-WX	0.100 0.100 0.100 0.100	0	0 (LN_2 Controls)	0	No Values	Potting compound pulled out of holder
9-10-63	9-10-63	10-1-EN 10-2-EN 10-3-EN 10-4-EN	0.046 0.046 0.046 0.046	1.1(10)	2.2(14) (LN_2 High Dose)	2.1(15)	No Values	Potting compound pulled out of holder

Table B-25

Radiation-Cryotemperature Test Data: EC-1949 (Material O)

Type of Test T-Peel

Type of Material Sealant

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Avg. T-Peel Strength per Inch Width (lb)	Comments
Irradiated	Tested			Gamma [ergs/gm(C)]	Neutron (n/cm^2) $E < 0.48$ ev	Neutron (n/cm^2) $E > 2.9$ Mev		
	5-14-63	0-X-1 0-X-2 0-X-3 0-X-4	1.00 1.00 1.00 1.00	0 (Ambient-air Controls)	0	0	158 149 156 167 158/9	
4-25-63	5-14-63	1-N1-1 1-N1-2	1.00 1.00	5.8(9) (Ambient-air Low Dose)	4.1(13)	1.1(15)	93 84 89/8	
4-25-63	5-14-63	2-N1-1 2-N1-2	1.00 1.00	1.1(10) (Ambient-air High Dose)	1.1(14)	2.1(15)	68 66 67/2	

Table B-26 (Rejections)

Radiation-Cryotemperature Test Data: EC-1949 (Material O)

Type of Test T-Peel Type of Material Sealant

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Avg. T-Peel Strength per Inch Width (lb)	Comments
				Gamma [ergs/gm(C)]	Neutron (n/cm^2)			
Irradiated	Tested				E < 0.48 ev	E > 2.9 Mev		
4-25-63	5-14-63	1-N1-3	1.00	5.8(9)	4.1(13) (Ambient-air Low Dose)	1.1(15)	x	Specimen ruined in pulling. Pen not on.
4-25-63	5-14-63	2-N1-3	1.00	1.1(10)	1.1(14) (Ambient-air High Dose)	2.1(15)	x	Specimen ruined in pulling. Pen and chart not on.
	4-19-63	2-4-WX 7-4-WX	No Values	0	0 (LN_2 Controls)	0	x x	No apparent breaks on chart.
4-25-63	4-25-63	2-4-WW 7-4-WW 8-4-WW	No Values	5.4(9) 4.6(9) 4.0(9)	1.6(14) 1.1(14) 7.7(14)	7.6(14) 6.9(14) 5.5(14)	x x x	No apparent breaks on chart.

Note: This material was not tested at LN_2 high dose.

Table B-27

Radiation-Cryotemperature Test Data: EC-1663 (Material P)

Type of Test T-Peel

Type of Material Sealant

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Avg. T-Peel Strength per Inch Width (lb)	Comments
Irradiated	Tested			Gamma [ergs/gm(C)]	Neutron (n/cm^2) $E < 0.48$ ev	Neutron (n/cm^2) $E > 2.9$ Mev		
	5-14-63	0-X-1 0-X-2 0-X-3 0-X-4	1.00 1.00 1.00 1.00	0	0 (Ambient-air Controls)	0	86 91 89 59 81/16	
4-25-63	5-14-63	2-N1-1 2-N1-2	1.00 1.00	1.1(10)	1.1(14) (Ambient-air Low Dose)	2.1(15)	8 29 19/19	
	4-19-63	4-4-WX	0.049	0	0 (LN_2 Controls)	0	83	

Table B-28 (Rejections)

Radiation-Cryotemperature Test Data: EC-1663 (Material P)

Type of Test T-Peel | Type of Material Sealant

Date		Specimen Code Number	Pull Speed at Break (in./min)	Radiation Exposure			Avg. T-Peel Strength per Inch Width (lb)	Comments
				Gamma [ergs/gm(C)]	Neutron (n/cm^2)			
Irradiated	Tested				$E < 0.48$ ev	$E > 2.9$ Mev		
4-25-63	5-14-63	2-N1-3	(see comments)	1.1(10)	1.1(14) (Ambient-air Low Dose)	2.1(15)	No Values	Specimen fell apart before pulling
4-25-63	5-14-63	3-N1-1 3-N1-2 3-N1-3	(see comments)	7.5(10)	5.7(14) (Ambient-air High Dose)	3.7(16)	No Values	All three specimens fell apart before pulling
	4-19-63	5-4-WX	0.044	0	0 (LN_2 Controls)	0	No Values	No apparent break
4-25-63	4-25-63	4-4-WW 5-4-WW 1-4-WW	0.100 0.100 0.200	9.3(9) 6.5(9) 9.0(9)	2.1(14) 1.4(14) 2.9(14) (LN_2 Low Dose)	1.2(15) 8.5(14) 1.5(15)	No Values	No apparent break
9-13-63	9-13-63	2-4-EN 4-7-EN 5-7-EN		6.7(10) 6.7(10) 5.1(10)	8.5(14) 8.0(14) 6.9(14) (LN_2 High Dose)	1.3(16) 1.2(16) 9.9(15)	No Values	No apparent break

APPENDIX C

DETERMINATION OF AN EQUATION TO MEASURE THE COEFFICIENT OF THERMAL CONDUCTIVITY USING THE CYLINDRICAL GEOMETRY APPROACH

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DETERMINATION OF AN EQUATION TO MEASURE THE COEFFICIENT OF THERMAL CONDUCTIVITY USING THE CYLINDRICAL GEOMETRY APPROACH

The coefficient of thermal conductivity is defined as the quantity of heat that will flow across a unit area in unit time if the temperature gradient between the two surfaces through which heat is flowing is unity. For heat flow through the flat surfaces of a material of thickness x, with flow perpendicular to the surface, the following relationship is thus established:

$$q/A = \frac{k}{x}(T_1 - T_2)$$

where

q/A = rate of heat flow through a unit area of the surface,

k = coefficient of thermal conductivity,

x = thickness of the material, and

$T_1 - T_2$ = ΔT across the thickness x (T_1 being the higher temperature).

The coefficient of thermal conductivity can also be defined as the proportionality constant between the heat per unit time crossing a unit area and the temperature gradient. The temperature gradient through a material can be expressed as the rate of change of temperature with change of distance (dT/dL) and is always measured in the direction of flow. Then, the rate of heat transmission by conduction across an area, A, of any homogeneous material is given for the steady-state condition by Fourier's law as

$$q = -kA \frac{dT}{dL}$$

The negative sign is used to give a positive value to q, since the temperature change in the direction of flow is negative. The above equation may be integrated as follows:

$$q \int_{L_1}^{L_2} \frac{dL}{A} = - \int_{T_1}^{T_2} kdT.$$

Now k will vary with temperature, or

$$k = f(T),$$

so that

$$q \int_{L_1}^{L_2} \frac{dL}{A} = - \int_{L_1}^{T_2} f(T)dT.$$

But the term

$$\frac{\int_{T_1}^{T_2} f(T)dT}{T_2 - T_1}$$

is the mean value of f(T) between T_1 and T_2, which in this case is equal to k_m, the mean value of k over this temperature range. Therefore,

$$q \int_{L_1}^{L_2} \frac{dL}{A} = -k_m (T_2 - T_1)$$

or

$$q = \frac{k_m (T_1 - T_2)}{\int_{L_1}^{L_2} \frac{dL}{A}} .$$

Hence, the term

$$- \int_{T_1}^{T_2} kdT$$

has been replaced by $k_m (T_1 - T_2)$, irrespective of the relation between A and L.

Now the equation

$$q = \frac{k_m (T_1 - T_2)}{\int_{L_1}^{L_2} \frac{dL}{A}}$$

may be written as

$$q = \frac{(T_1 - T_2)}{\frac{1}{k_m} \int_{L_1}^{L_2} \frac{dL}{A}}$$

In this form, the equation may be compared to Ohm's law in electrical circuits,

$$I = \frac{E}{R} ,$$

where the term

$$\frac{1}{k_m} \int_{L_1}^{L_2} \frac{dL}{A}$$

can be regarded as the thermal resistance, or R_t.

Then,

$$q = \frac{T_1 - T_2}{R_t} .$$

The geometry for radial conduction through thick-walled cylinders is shown in Figure C-1. If the area A for an annulus of length h is $2\pi rh$ and the thickness is dr, then

$$R_t = \frac{1}{k_m} \int_{L_1}^{L_2} \frac{dL}{A}$$

$$= \frac{1}{k_m} \int_{r_1}^{r_2} \frac{dr}{2\pi rh} = \frac{1}{2\pi k_m h} \left(\ell n \frac{r_2}{r_1} \right) .$$

If this expression for R_t is substituted into the above equation for q, and the diameter ratio D_2/D_1 is substituted for r_2/r_1, then

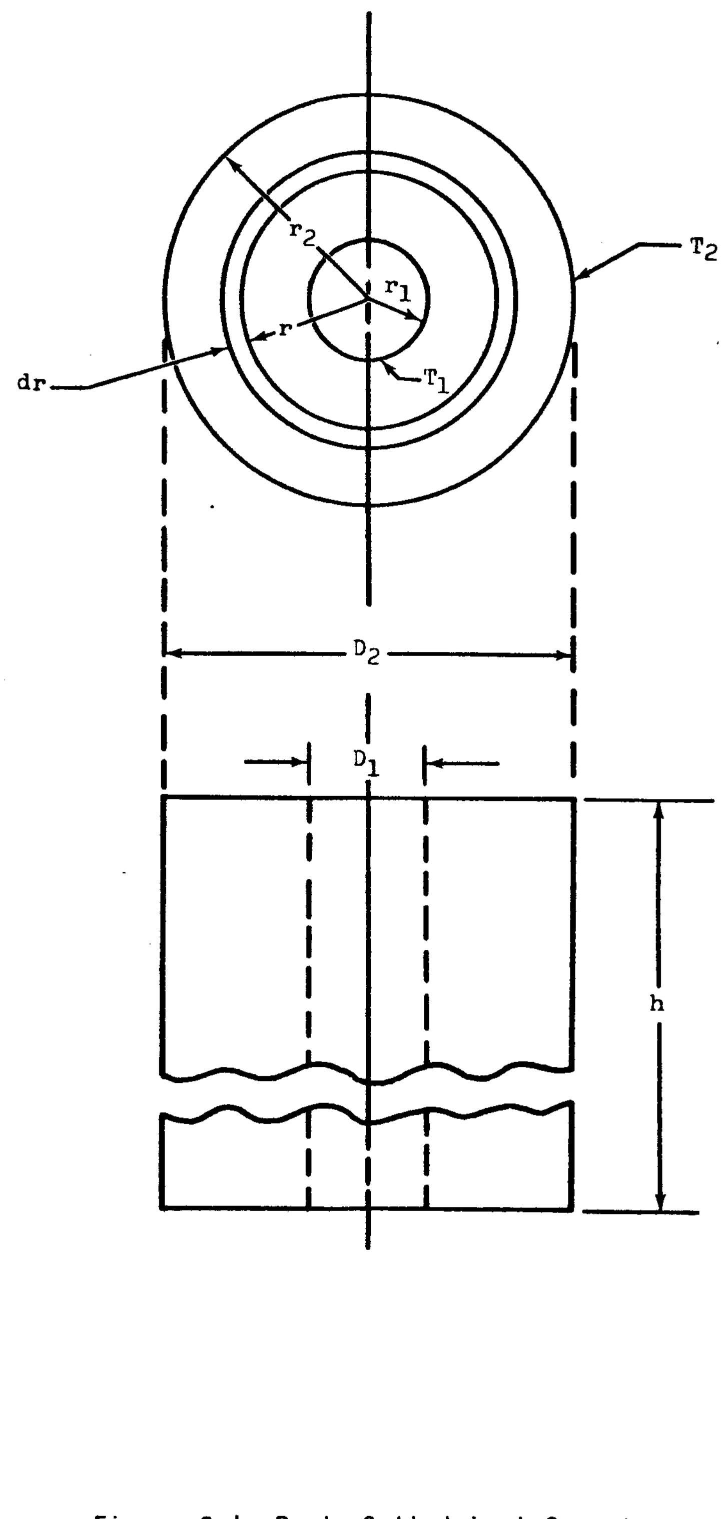

Figure C-1 Basic Cylindrical Geometry

$$q = \frac{2\pi h k_m (T_1 - T_2)}{\ell n (D_2/D_1)} \cdot$$

If concentric cylinders of different materials are used, the composite thermal resistance is equal to a summation of the individual resistances. In other words, it represents, in the electrical analog, a series system.

If there are two concentric cylinders consisting of materials with different coefficients of thermal conductivity, and the system is in a steady-state condition,

$$q = \frac{2\pi h(T_1 - T_3)}{\frac{1}{k_{m_1}} (\ell n \frac{D_2}{D_1}) + \frac{1}{k_{m_2}} (\ell n \frac{D_3}{D_2})}$$

where k_{m_1} = k for inner cylinder,

k_{m_2} = k for outer cylinder.

D_2 = Outer diameter of outer cylinder

and T_3 = Temperature of outer edge of outer cylinder

From the above equation for q,

$$\frac{1}{k_{m_1}} (\ell n \frac{D_2}{D_1}) + \frac{1}{k_{m_2}} (\ell n \frac{D_3}{D_2}) = \frac{2\pi h(T_1 - T_3)}{q}$$

or

$$\frac{1}{k_{m_1}} (\ell n \frac{D_2}{D_1}) = \frac{2\pi h(T_1 - T_3)}{q} - \frac{1}{k_{m_2}} (\ell n \frac{D_3}{D_2})$$

and

$$\frac{1}{k_{m_1}} = \frac{2\pi h(T_1 - T_3)/q}{\ell n \frac{D_2}{D_1}} - \frac{\frac{1}{k_{m_2}} (\ell n \frac{D_3}{D_2})}{\ell n \frac{D_2}{D_1}}$$

The planned test involved the measurement of k for various foam-type thermal-insulation materials. A system of three concentric cylinders was used (Fig. C-2). Since the inner cylinder was the heat source, only the middle and outer cylinders were significant in calculations of heat flow out from the center heater. In this test, the middle cylinder was a foam test specimen, and the outer cylinder was an aluminum outer casing. Therefore, k_{m_1} in the above equation is k for the foam and k_{m_2} is k for the outer casing. An approximate value for k_{m_1}/k_{m_2} is 0.0002. Also the term D_3/D_2 is approximately equal to 1.09. So, for all practical purposes,

$$\frac{1}{k_{m_2}} (\ell n \frac{D_3}{D_2}) = 0.$$

Therefore, for this test,

$$k_{m_1} = \frac{q (\ell n \frac{D_2}{D_1})}{2\pi h(T_1 - T_2)}$$

where T_2 and T_3 are considered to be equal because of the high coefficient of thermal conductivity of the aluminum outer casing.

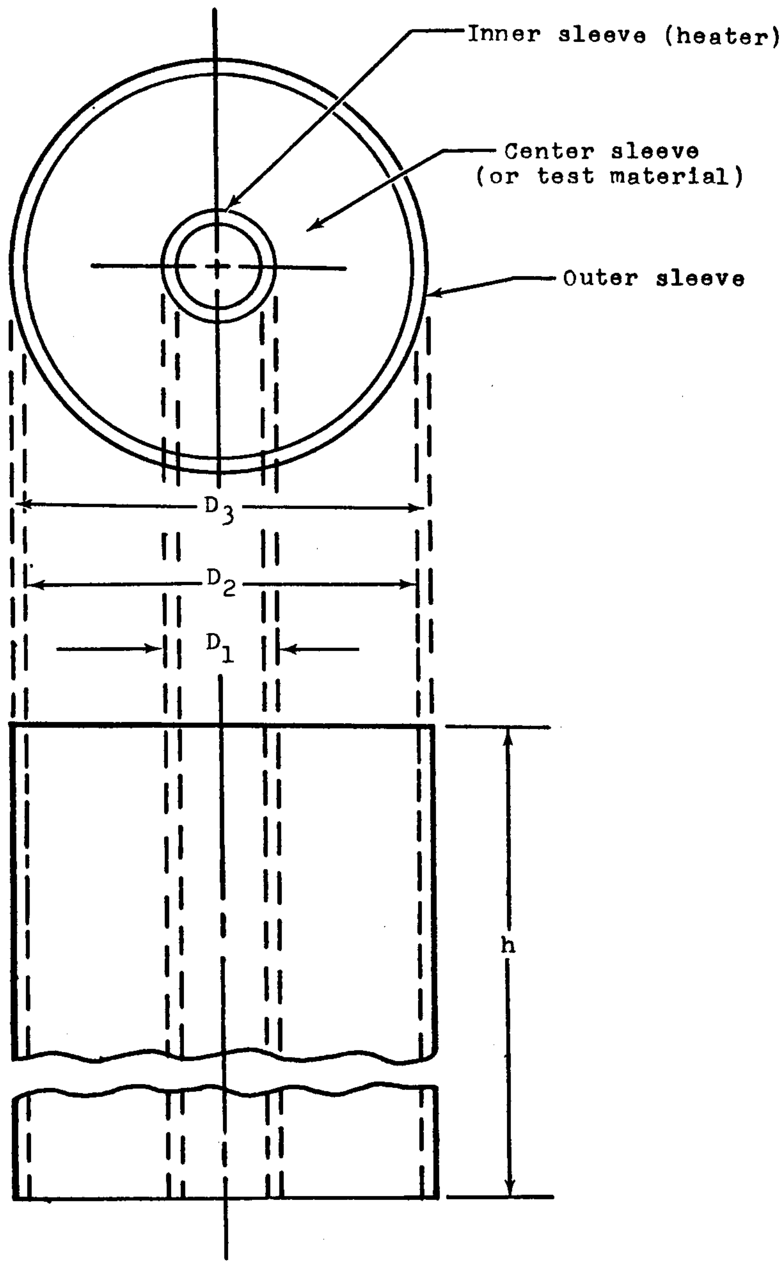

Figure C-2 Cylindrical Geometry for Three Concentric Cylinders of Different Materials

Validity of the above expression for k_{m_1} (which is k for the test material) depends upon the complete expenditure of the heat q radially through the test specimen, and over the total length h.

APPENDIX D

OPERATIONAL CHECKOUT TEST
FOR LIQUID-NITROGEN DEWAR

APPENDIX D

OPERATIONAL CHECKOUT TEST FOR LIQUID-NITROGEN DEWAR

The main purpose of this test was to demonstrate the possibility of conducting safe, explosion-free tests that involve the irradiation of dewars containing large amounts of boiling liquid nitrogen. During the course of a test, the amount of liquid nitrogen that is boiled off approaches hundreds or even thousands of gallons. The operational checkout test was instigated at NARF as a result of the occurrence of several small detonations in LN_2 dewars during past irradiation tests at the facility.

D-1 History

After the 22 April 1963 irradiation tests, inspection of the west dewar revealed that the walls to the main cryogen chamber had ruptured at the welds around the bottom (see Fig. 3.3). An investigation was begun immediately to determine what had taken place and why.

Since nothing of an unusual nature had occurred during the tests, a check was made of the cryogen-chamber pressure-transducer recorder chart for the period during postirradiation warm-up. Six pressure pips, spaced approximately 10 min apart, were found to be recorded on the chart about 6 to 8 hr after shutdown of both the reactor and the LN_2 flow. This happens to be the approximate time required to boil off a 16-gal chamber of LN_2. It was also ascertained that personnel in the reactor area had heard a sound resembling a muffled explosion at about the time the pressure pips were recorded.

It is known that ozone is formed by irradiation of oxygen, and reference to the boiling point of LOX and LN_2 revealed that LOX impurities in continuously supplied boiling LN_2 would build up in concentration. A check of the sources of supply for LN_2 delivered to NARF during 1962 showed that those sources used (when several LN_2 irradiations were carried out without incident) had supplied LN_2 with a guaranteed LOX content of less than 20 ppm.

On the other hand, the LN_2 used in 1963 (for the irradiation tests involving the detonations described above) all came from a source which furnished tank analyses showing an LN_2 purity of 99.8%. The possibility that the remaining 0.2% could be mostly LOX thus indicates that in the process of boiling off as much as 5000 gal of LN_2, the LOX content in the dewar could gradually build up to a total of approximately 5 to 10 gal. With this amount of oxygen being transformed into ozone, resultant ozone dissociation reactions could very well be severe.

D-2 Technical Considerations

Evidence has pointed out the fact that LOX impurities exist in commercially supplied LN_2 in a concentration of up to 0.2%. Also, it is known that LOX, with a boiling point of 90^oK, will, when mixed with boiling LN_2 at 77.4^oK, remain in the liquid state. Therefore, it can be calculated that when from 1000 to 2000 gal of commercial LN_2 are boiled off in a large dewar, LOX in amounts approaching several gallons could be accumulated.

Two additional facts dovetail into the overall picture. First, molecular oxygen, under the influence of nuclear radiation, transforms into ozone (Ref. 10). Whatever the mechanism is for the overall ozone yield, radiation initially produces ions, atoms, and excited molecules in the oxygen. These species may be produced by reactions such as the following:

$$O_2 \rightsquigarrow O_2^+ + e^- \qquad (1)$$

$$O_2 \longrightarrow O_2^- \text{ or } O + O^- \qquad (2)$$

$$O_2 \rightsquigarrow O^+ + O + e^- \text{ or } O^+ + O^- \qquad (3)$$

$$O_2 \rightsquigarrow O_2^* \text{ or } O + O. \qquad (4)$$

Ozone may then be formed by many reactions, some of the more important of which are:

$$\begin{aligned} O_2^+ + O_2^- &\rightarrow O_3 + O \qquad (5) \\ &\rightarrow O_2^* + O_2 \\ &\rightarrow O_2 + O^* + O \\ &\rightarrow O_2 + O^* + O^* \end{aligned}$$

$$O + O_2 + M \rightarrow O_3 + M \qquad (6)$$

$$O_2 + O_2^* \rightarrow O_3 + O. \qquad (7)$$

---

* The asterisk (*) in the formulas indicates a molecule or atom in an activated state.

Second, this radiation-produced ozone will then, under the influence of organic or other types of sensitizers and of catalysts (M), dissociate into molecular and atomic oxygen according to such reactions as

$$O_3 + M \longrightarrow O_2 + O + M \qquad (8)$$

$$O + O_3 \longrightarrow 2\,O_2. \qquad (9)$$

These dissociation reactions are highly exothermic and may, under proper conditions of confinement, be explosive.

A vivid enactment of this chain of events (which is in addition to the incident described above) is believed to have taken place during a SNPO irradiation at NARF during the third week of May 1963. A dewar of 20-gal capacity was filled with LN_2 and irradiated at various reactor power levels for a period of 16 hr. During this time, the LN_2 was boiling out of the dewar at a rate of from 20 to 40 gal/hr, with the loss being continuously made up from an outside supply tank. The reported purity of LN_2 in the supply tank was 99.8% with the remaining 0.2% being mostly LOX.

At the end of the irradiation run, the dewar was positioned on the horizontal track of the escalator (shuttle) system and the LN_2 supply shut off. Approximately 4 hr later (this period of time being just about sufficient to boil off a subcooled dewar of LN_2), several loud detonations occurred in the dewar and witnesses noticed a distinct odor of ozone in the area.

On the basis of calculated (and measured) LN_2 boil-off rates during irradiation tests of existing dewars, it has been determined that anywhere from 1000 to 3000 gal of LN_2 will be consumed in a 50-hr test. From this it can therefore be assumed that use of LN_2 with a purity of 99.8% or less in these dewars could result in ozone explosions during irradiation tests. On the other hand, it can also be assumed that if LN_2 with a guaranteed LOX content of less than 20 ppm is used, any ozone formed will be insufficient in quantity to produce detectable detonations. This test was an attempt to establish a high degree of reliability for the latter assumption.

D-3 Test Description

The checkout test, using modified NASA dewars built at NARF under NASA Contract NAS8-2450, was conducted at NARF with the GTR as the radiation source. The dewar (Fig. D-1) is a four-walled, all-aluminum vessel which, after modifications from the original design, utilizes a double-reverse path for evaporated cryogen to act as thermal insulation for the central cryogen chamber. The outermost chamber contains a SiO_2 thermal-insulation material.

The test consisted of irradiating the dewar for a 13-hr period, during which time approximately 400 gal of LN_2 (with a tested LOX content of less than 20 ppm) was boiled away in the cryogen chamber. During the run, the temperature of the bottom of the cryogen chamber was monitored to detect any change from that of LN_2, since a different temperature would indicate the presence of a significant amount of LOX or ozone.

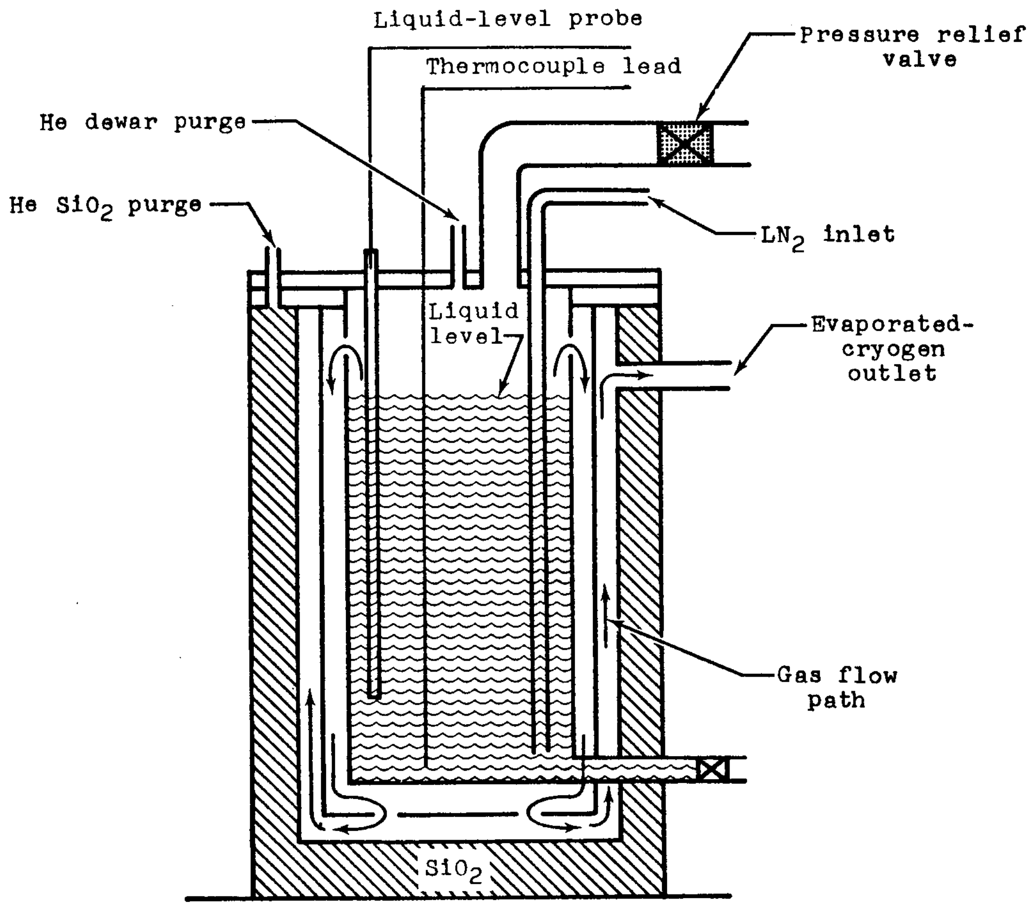

Figure D-1 Modified NASA Dewar

At the end of the irradiation period, with the chamber still filled, a 1-gal sample of the contents of the bottom of the chamber was retrieved and allowed to boil away in a restricted area to check on the possible presence of LOX or ozone.

D-3.1 Experimental Equipment

The dewar shown in Figure D-1 was used. It was fastened to the underside of a standard NASA tensile assembly that served as a top cover for the cryogen chamber. The dewar contained 4000 cc of lead to provide an added source of gamma heating and thus increase the LN_2 boil-off rate. A 500-gal portable LN_2 supply tank was used with an Armaflex-insulated, 1/2-in. soft-copper supply line. Temperature in the bottom of the cryogen chamber was monitored with a Brown recorder and a copper-constantan thermocouple. A liquid-level probe was attached to the underside of the dewar mounting plate. A pressure relief valve was mounted on the mating flange of the upper tensile assembly and served to relieve any pressure in the cryogen chamber in excess of 7-1/2 psi. Helium under low pressure was fed into the dewar during the run from a helium bottle and regulator.

Evaporated cryogen was bled out of the dewar through a 1-in. gate valve. A cylinder of helium gas was used with a pressure regulator to purge the entire system prior to initiation of the LN_2 flow. Sampling of the liquid in the bottom of the cryogen chamber at the end of the run was accomplished by pressurizing the dewar to 7 psi and forcing LN_2 back out the supply line and into a 1-gal open dewar.

D-3.2 Test Procedure and Results

The dewar, with attached tensile assembly, was positioned in the support framework, which then was attached to an escalator pallet on the horizontal tracks just north of the handling area in the GTR Radiation Effects Test Facility. Helium gas was then applied to the SiO_2 packing in the dewar under 5 psi for a 1-hr period. This thoroughly permeated the SiO_2 fibers with helium. A thermocouple harness, a liquid-level harness, an LN_2 supply line, a helium supply line, an evaporated cryogen outlet line, and a pressure relief valve were attached to the proper connections on the dewar cover plate (Fig. D-2). The entire assembly was then lowered into irradiation position.

With the LN_2 supply line disconnected at the supply tank, the entire system was purged with helium gas through a connection on top of the dewar. The helium supply was then shut off, the gate valve on the end of the evaporated-cryogen outlet opened wide, the LN_2 supply line connected to the tank, and LN_2 flow started. The dewar-filling operation proceeded normally and, when the liquid level reached the top resistor on the liquid-level probe, LN_2 flow was reduced to match the boil-off rate. The reactor was then started, brought to a 3-Mw power level, and operated for a 13-hr period. The boil-off rate during the test varied from a maximum of 35 gal/hr at the beginning of the test, before the dewar had subcooled, to a minimum rate of 18 gal/hr. The average rate was 20 gal/hr. This was with the dewar located on the west irradiation pallet, with the reactor operating at 3-Mw, and with 4000 cc of lead in the cryogen chamber.

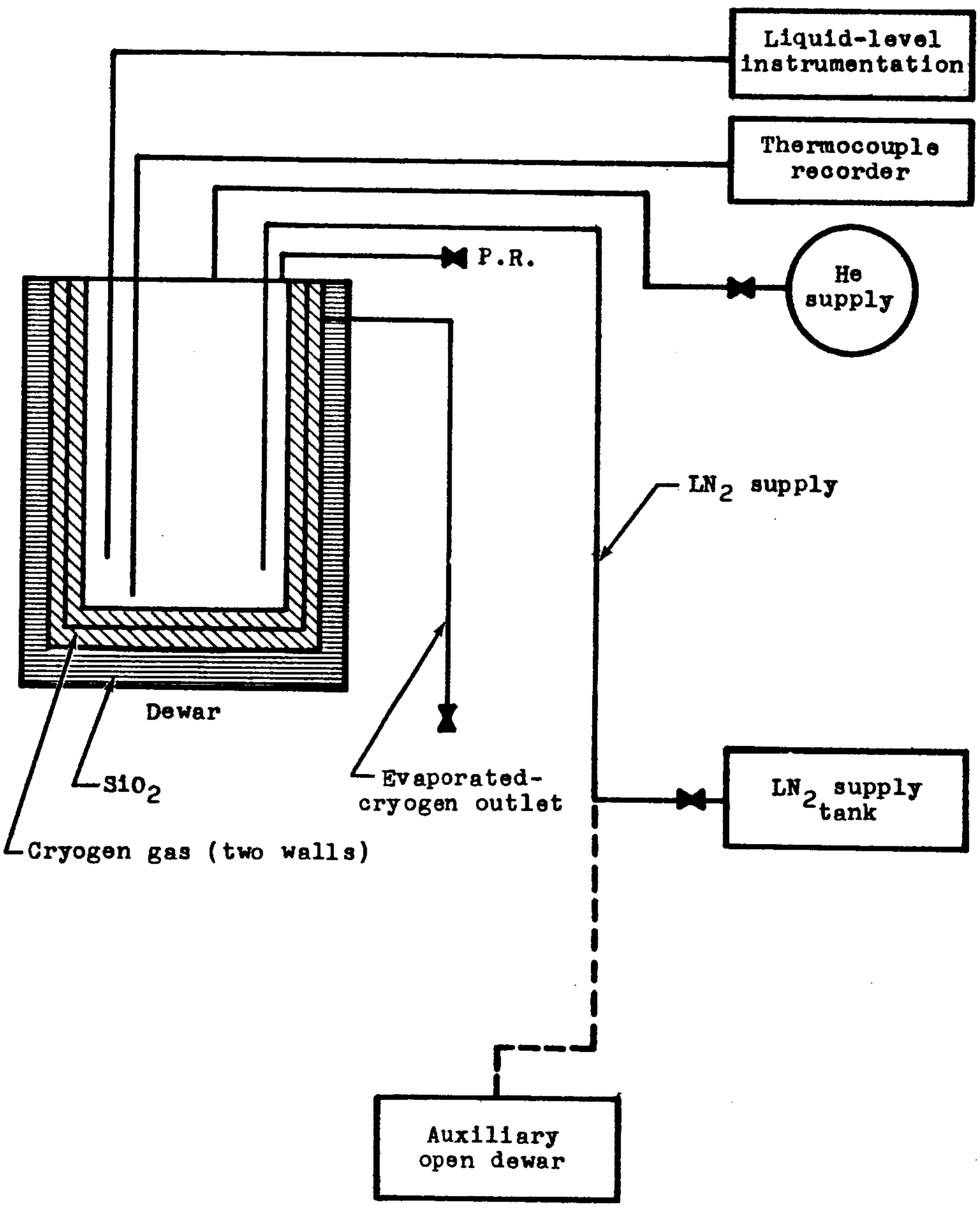

Figure D-2 Flow Diagram of LN_2 Dewar Test Equipment

After completion of the run, the reactor was retracted, the LN_2 supply shut off, and the assembly raised from irradiation position to the top edge of the pool. The LN_2 supply line was then disconnected from the supply tank and diverted to the open 1-gal dewar. The valve on the end of the evaporated-cryogen outlet line was slowly closed and pressure inside the dewar monitored with the pressure transducer. Pressure in the system rose gradually as a result of cryogen boil-off in the dewar and leveled off at 7 psi. This pressure then forced LN_2 out of the dewar and back through the LN_2 supply line. The supply line had warmed up in an interim period and most of the contents of the dewar flashed to gas before reaching the small, open, specimen dewar. Liquid flow from the line began eventually, however, and a 1-gal specimen was obtained. During the initial flow of gas, a mild odor of ozone was detected, but it had disappeared by the time the liquid was collected.

This liquid specimen was allowed to boil away and was observed during the boil-off period by personnel wearing protective clothing and face shields. During boil-off, the remaining liquid gradually turned dark blue in color, possibly implying the presence of ozone. No odor of ozone was detected, however, and no detonations occurred.

Nothing unusual was noticed by instrumentation for the test dewar during the 13-hr irradiation period, and no explosions were heard. No pressure or temperature changes were recorded and boil-off rates were normal. After completion of the purging operation at the end of the test, the dewar was opened and examined. Neither changes in the structure nor any other evidence of detonations were found.

D-4 Future Operational Procedures for NASA Dewars

D-4.1 Structural Modifications

To comply with planned operational procedures, two structural modifications to the dewars were necessary. These were (1) installation of a 1-in. drain line from the inside bottom of the cryogen chamber, through the four walls of the structure, to the outside, and (2) reinforcement of the third wall out from the center of the dewar with 1/4-in.-thick aluminum plate on all four sides and bottom.

The drain line was installed flush with the location of the cryogen chamber to permit complete drainage of any liquid in the chamber. A two-way solenoid valve was installed at the outlet of this line. The 1/4-in.-thick plates were welded to the existing third wall out from the center of the dewar and are, in addition, welded, plate-to-plate, at the edges. The next-to-outer chamber of the dewar (Fig. D-1) was pressure-checked to 20 psi.

D-4.2 Operational Procedures

Subsequent irradiation tests at NARF which involved the evaporation of large quantities of LN_2 utilized the NASA dewars (Fig. D-1) with modifications as described above. Standard procedure during operation included use of a liquid-level sensor, a pressure transducer to monitor dewar pressure continuously, a pressure relief valve, a continuous helium purge in the cryogen chamber, and continuous temperature measurement. A preirradiation purge of the SiO_2 insulation in the outer chamber was also made.

The results of the test described above went far toward establishing an explosion-free reliability for liquid-nitrogen irradiation tests that use only ultra-pure (20 ppm or less) LN_2. Modifications to the dewar as described above made possible the use of an added safety feature. Instead of merely boiling off the LN_2 in the dewar, the contents of the cryogen chamber could be purged by either of two methods. First, the solenoid valve in the end of the 1-in. drain line at the bottom of the cryogen chamber could be opened remotely and the contents drained out by gravity flow. Second, the pressure relief valve could be set at 15 psi, the evaporated cryogen outlet line valved off, the solenoid valve closed, the LN_2 supply line unhooked at the supply tank, and helium pressure applied through the purge line to force liquid back out the LN_2 supply line. This purging operation could take place, say, every 8 hr during an irradiation run to eliminate any possibility of an increase in LOX or ozone concentration.

APPENDIX E

STRESS-STRAIN CURVES OF LAMINATE TEST MATERIALS

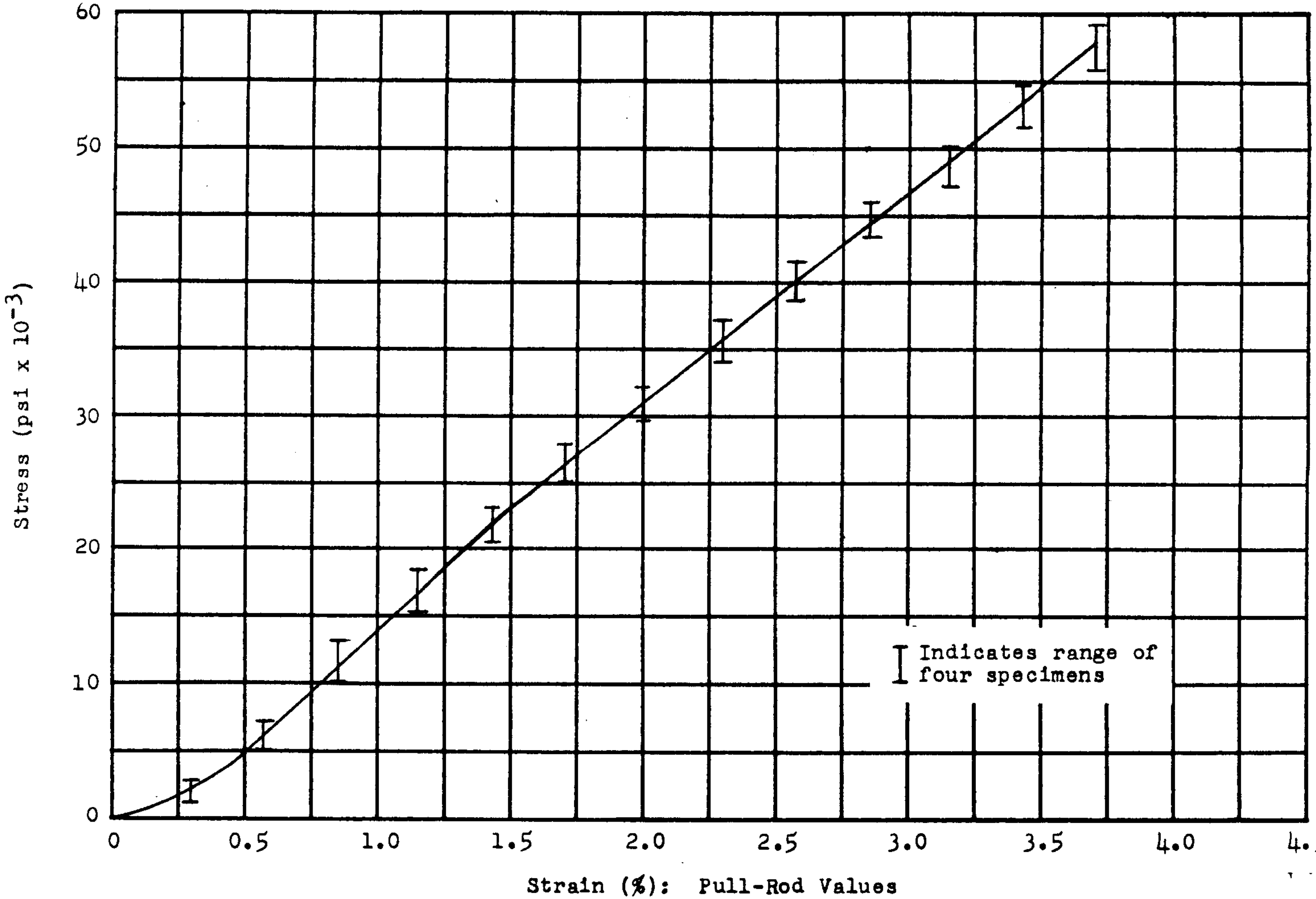

Figure E-1 Stress-Strain Curve (PRV) of Lamicoid 6038E (Electrical Insulation J) at Ambient Temperature: Preirradiation Control Run

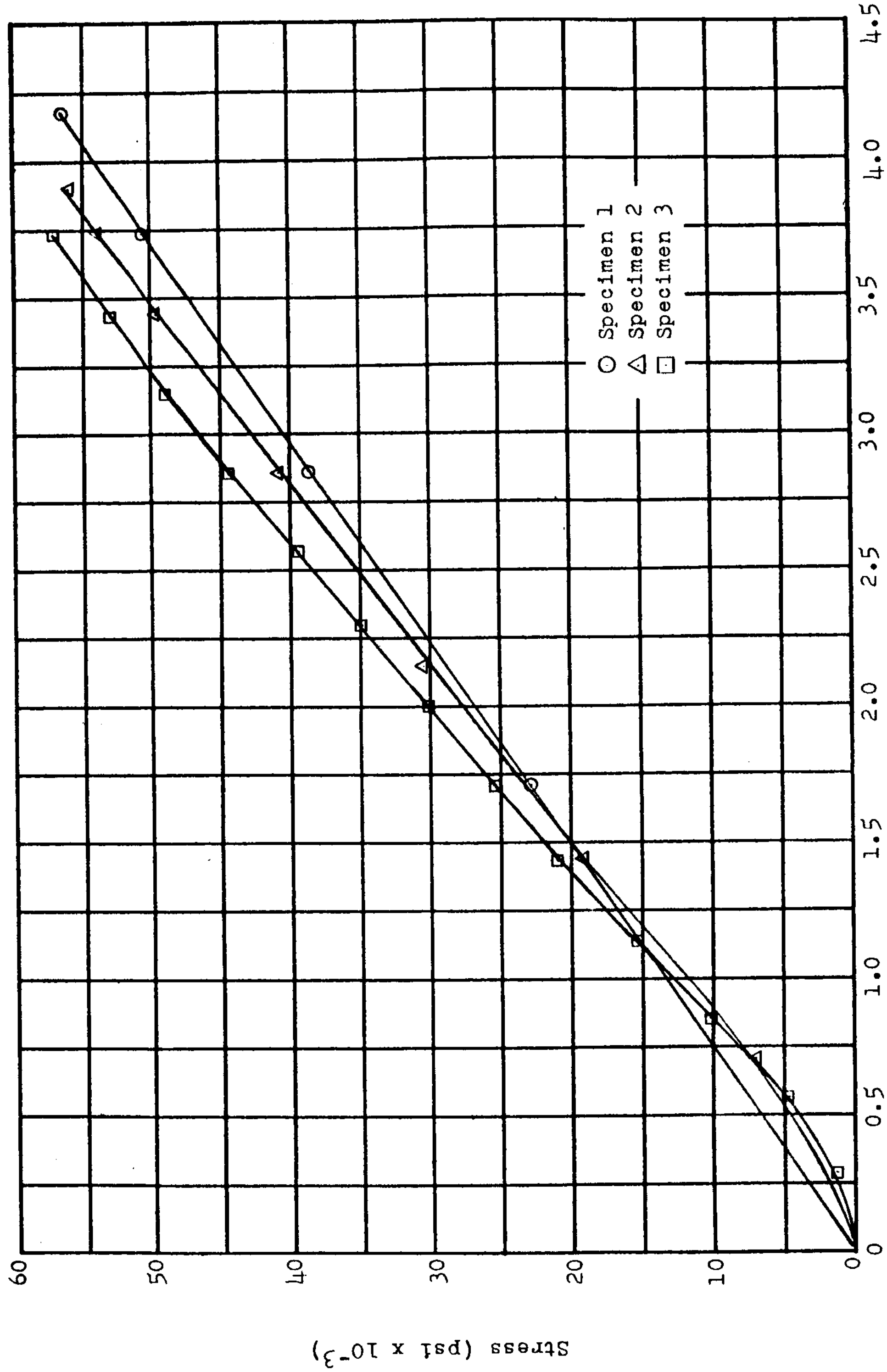

Figure E-2 Stress-Strain Curve (PRV) of Lamicoid **6038E** (Electrical Insulation J) at Ambient Temperature: Low-Dose Exposure

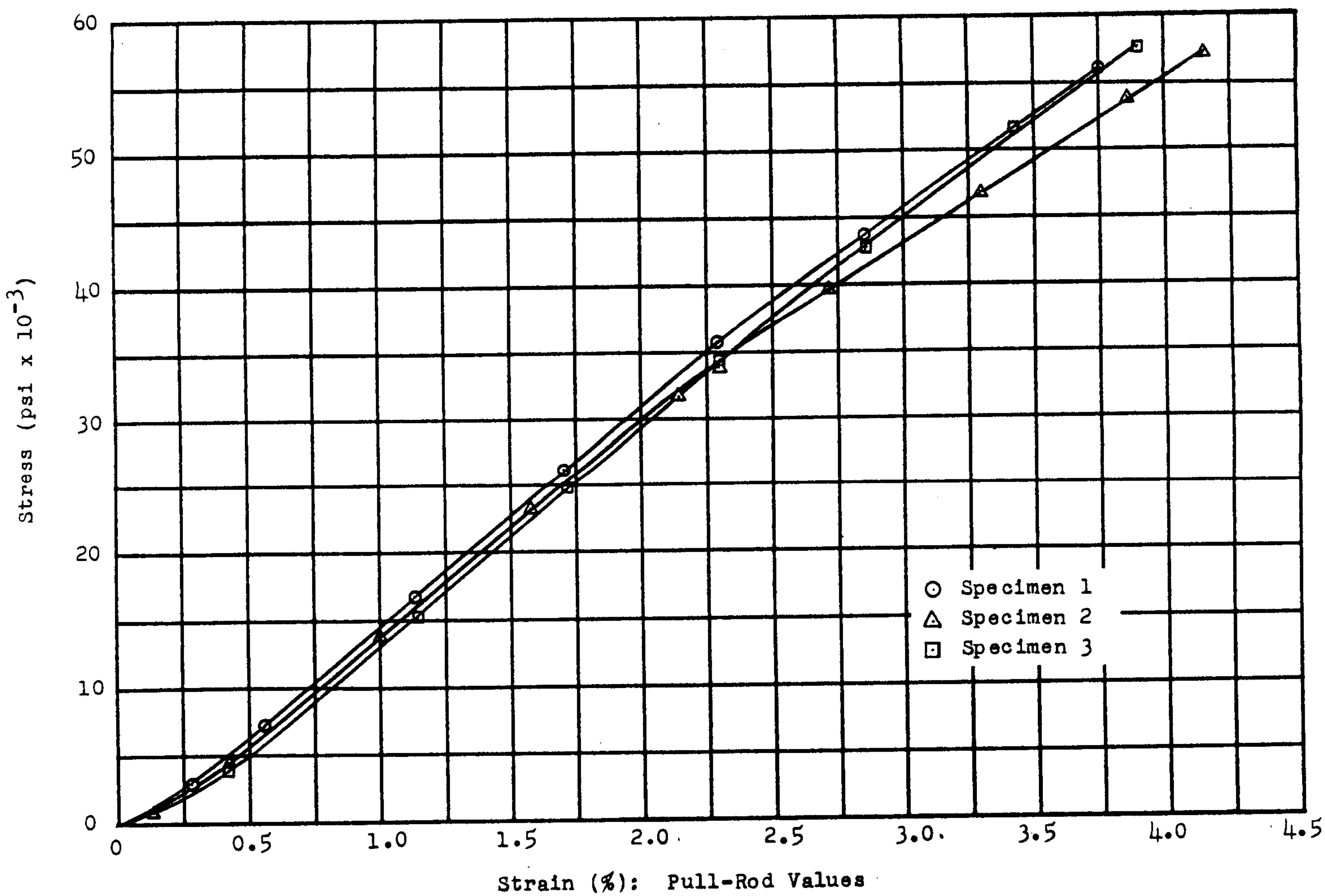

Figure E-3 Stress-Strain Curve (PRV) of Lamicoid 6038E (Electrical Insulation J) in Ambient Temperature: High-Dose Exposure

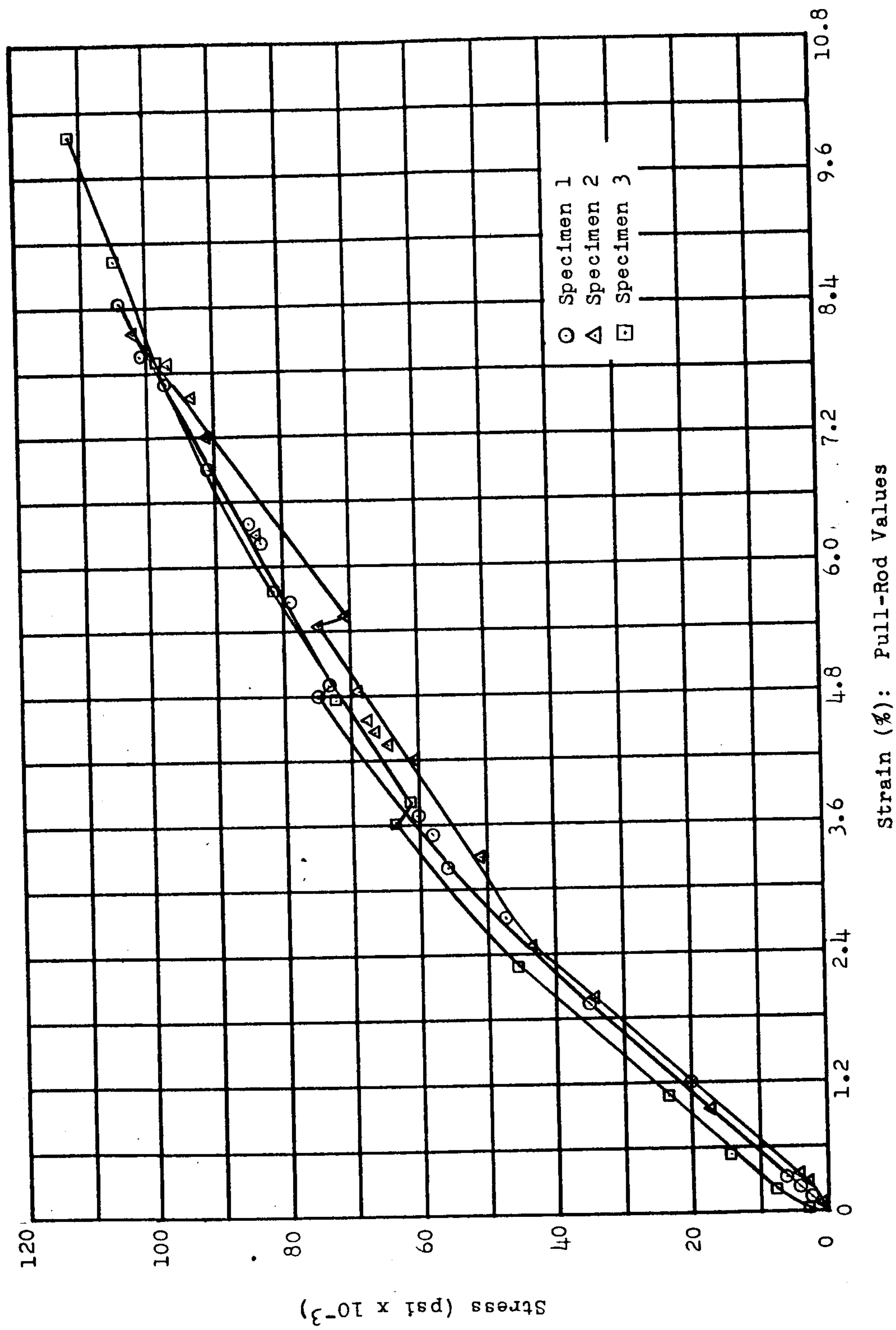

Figure E-4 Stress-Strain Curve (PRV) of Lamicoid 6038E (Electrical Insulation J) in LN_2: Preirradiation Control Run

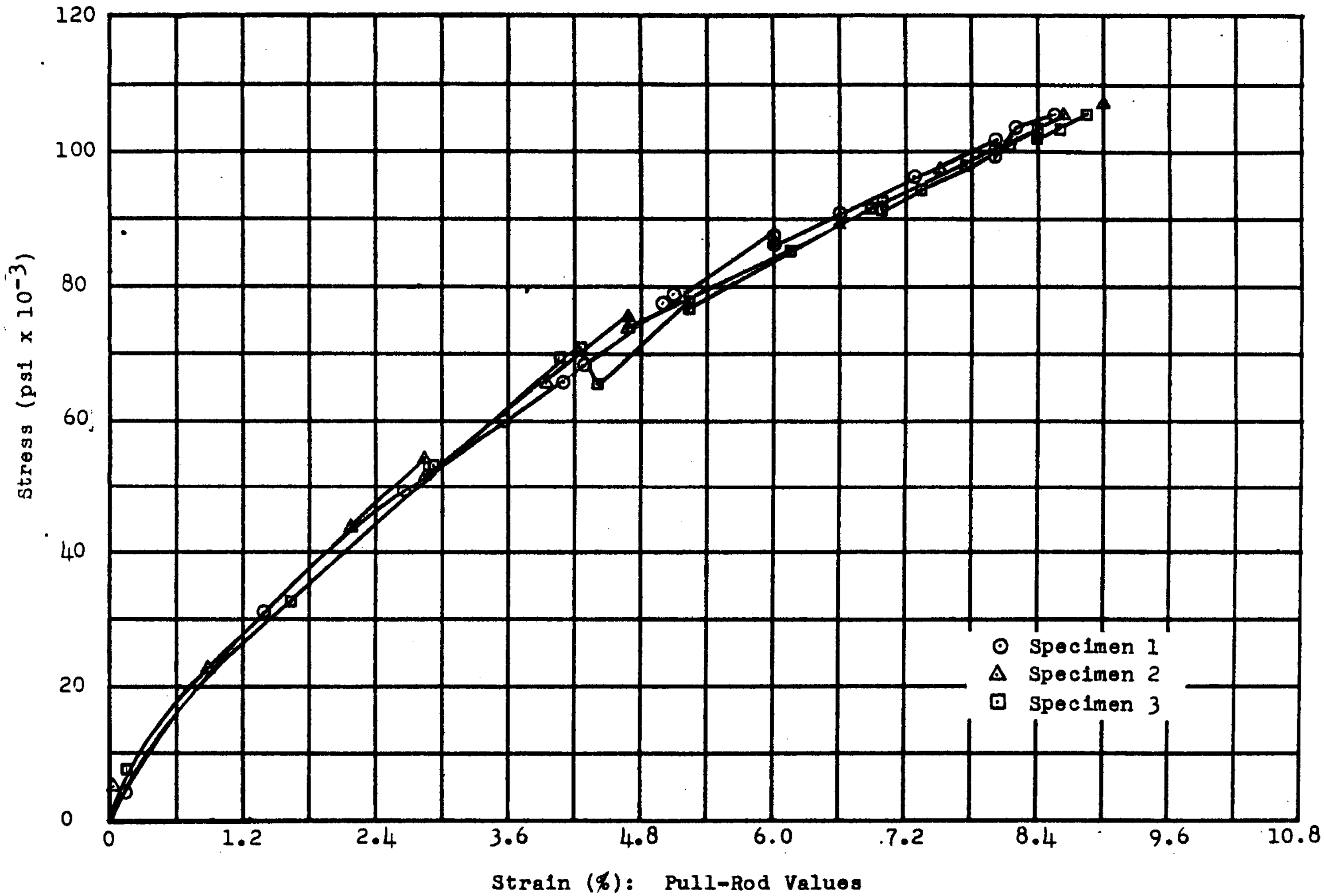

Figure E-5 Stress-Strain Curve (PRV) of Lamicoid 6038E (Electrical Insulation J) in LN_2: Low-Dose Exposure

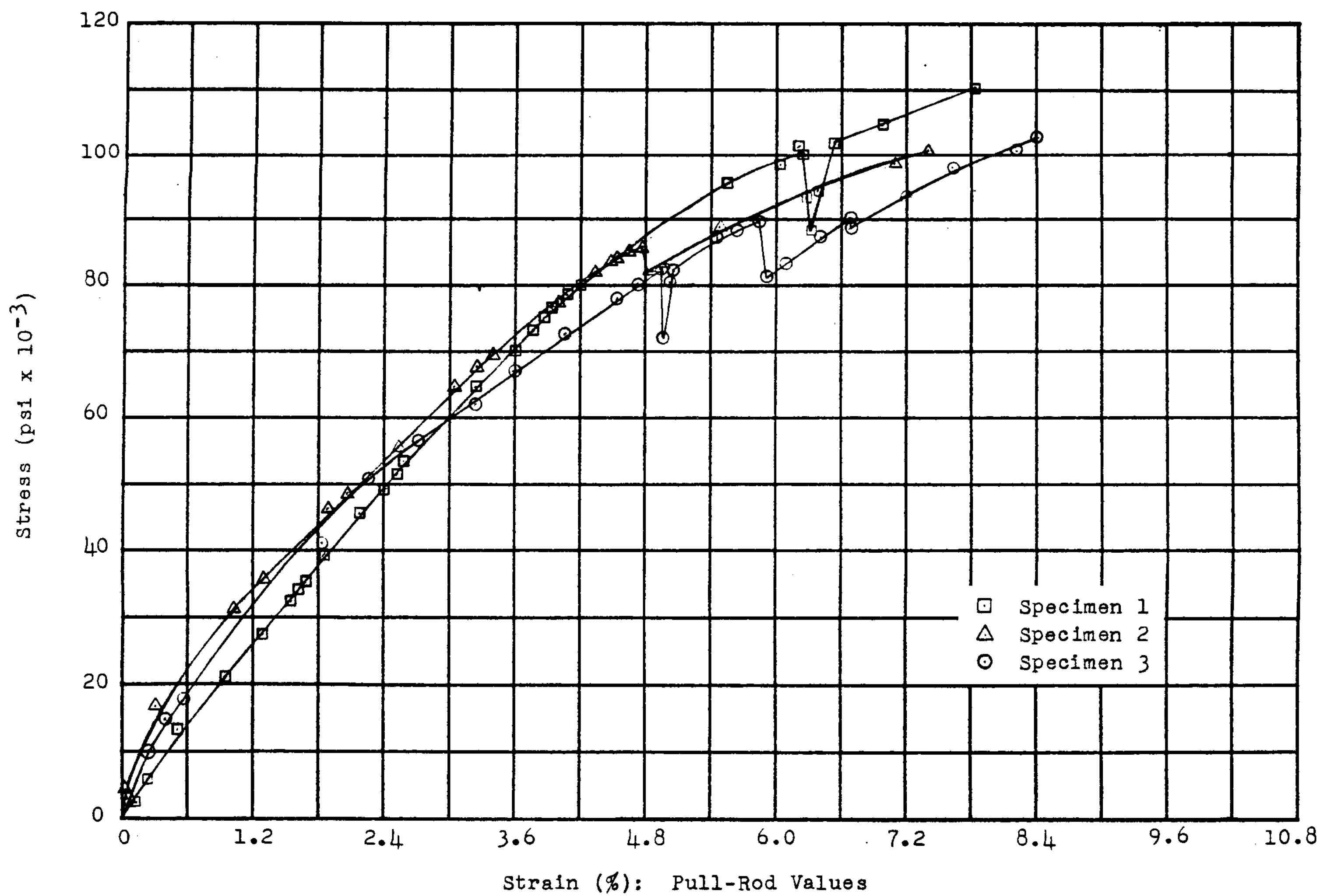

Figure E-6 Stress-Strain Curve (PRV) of Lamicoid 6038E (Electrical Insulation J) in LN_2: High-Dose Exposure

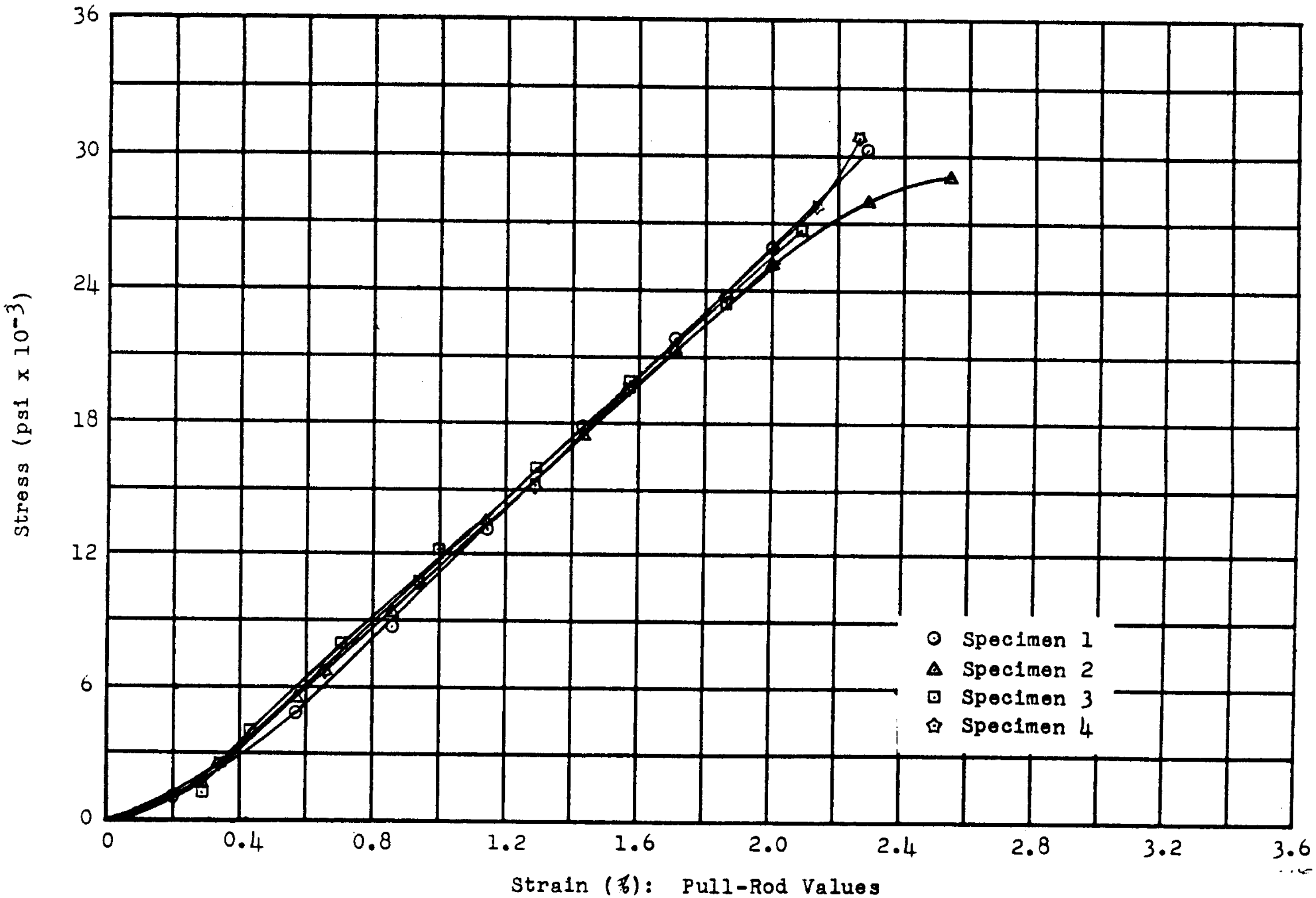

Figure E-7 Stress-Strain Curve (PRV) of CTL-91LD (Structural Laminate K) at Ambient Temperature: Preirradiation Control Run

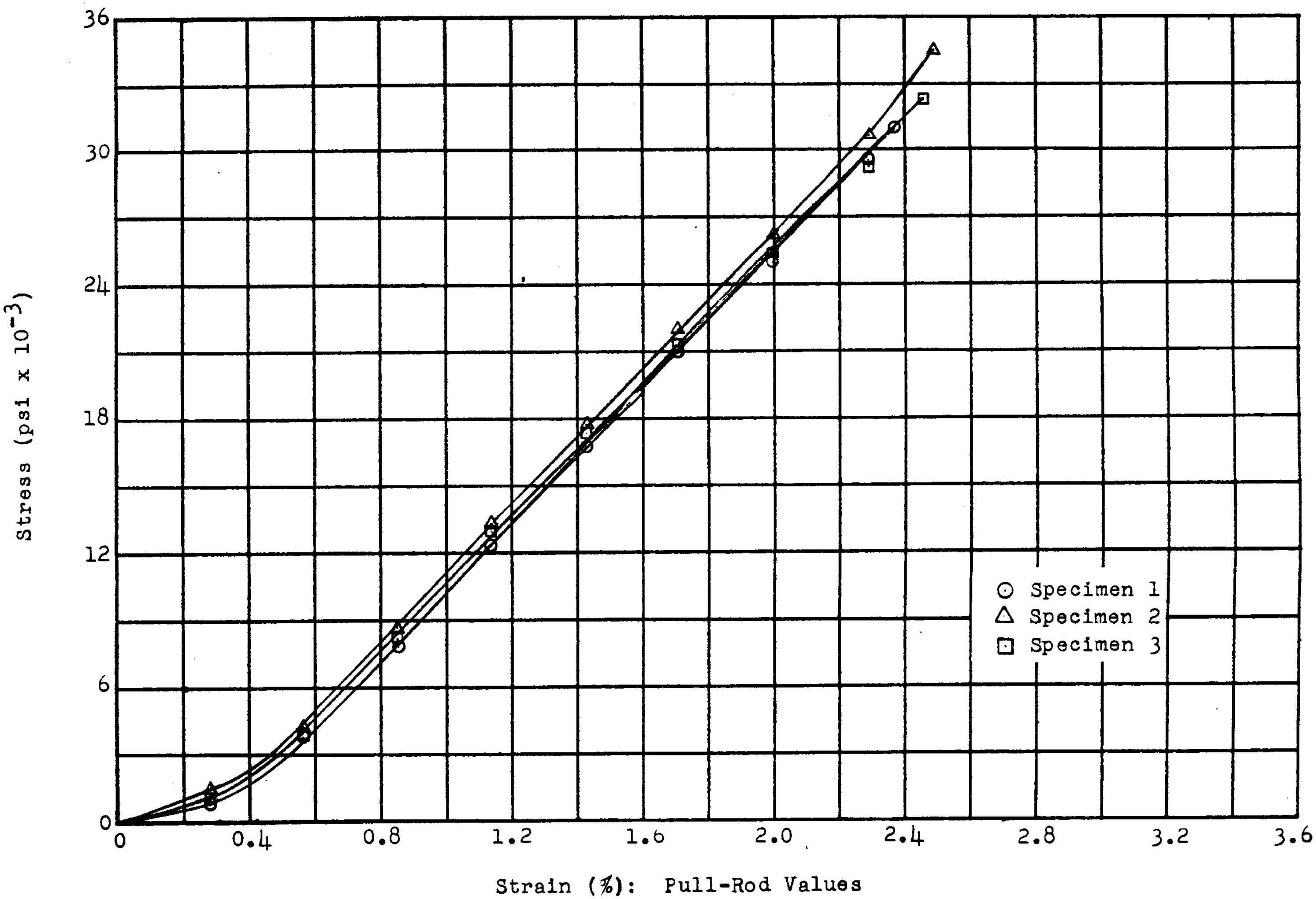

Figure E-8 Stress-Strain Curve (PRV) of CTL-91LD (Structural Laminate K) at Ambient Temperature: Low-Dose Exposure

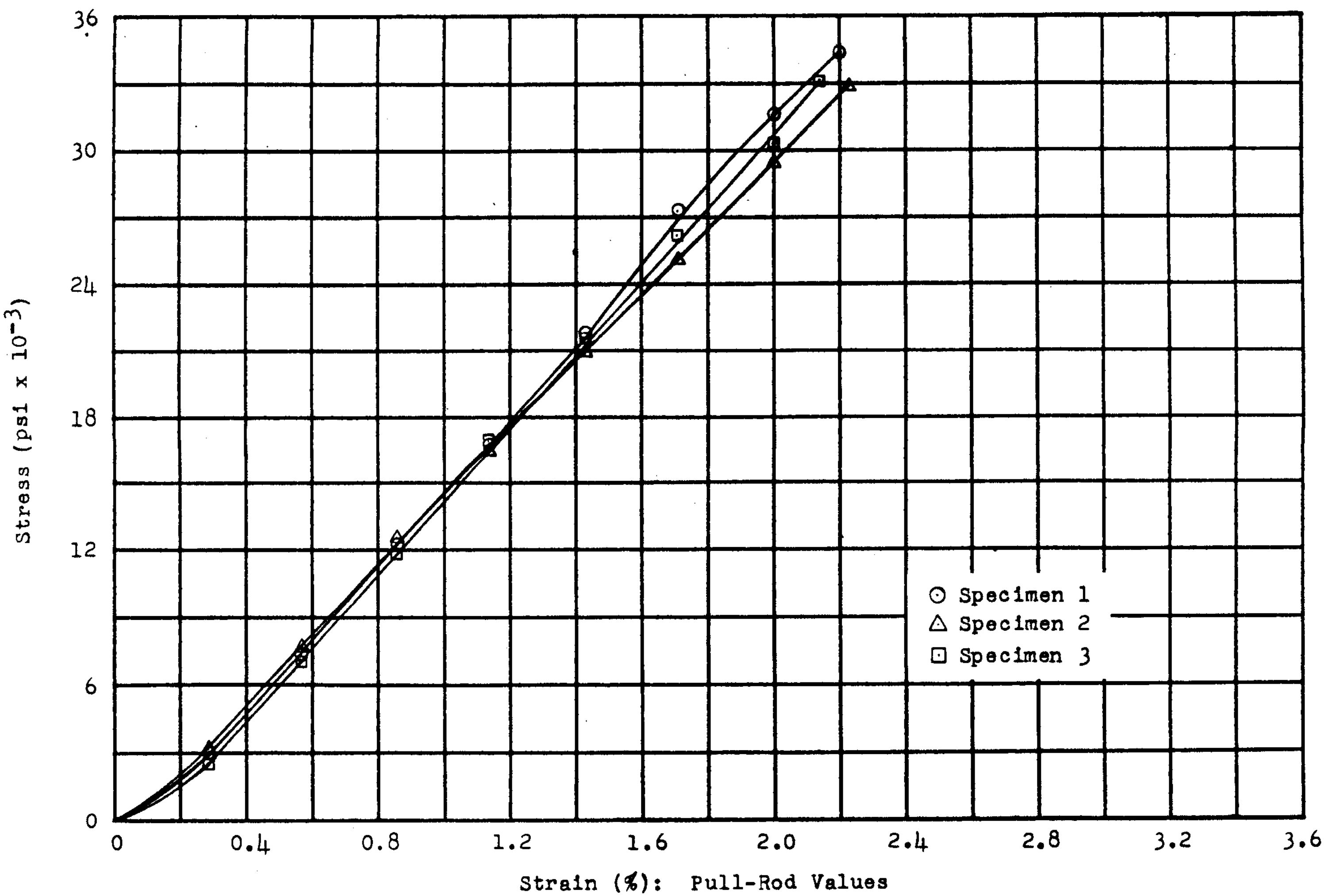

Figure E-9 Stress-Strain Curve (PRV) of CTL-91LD (Structural Laminate K) at Ambient Temperature: High-Dose Exposure

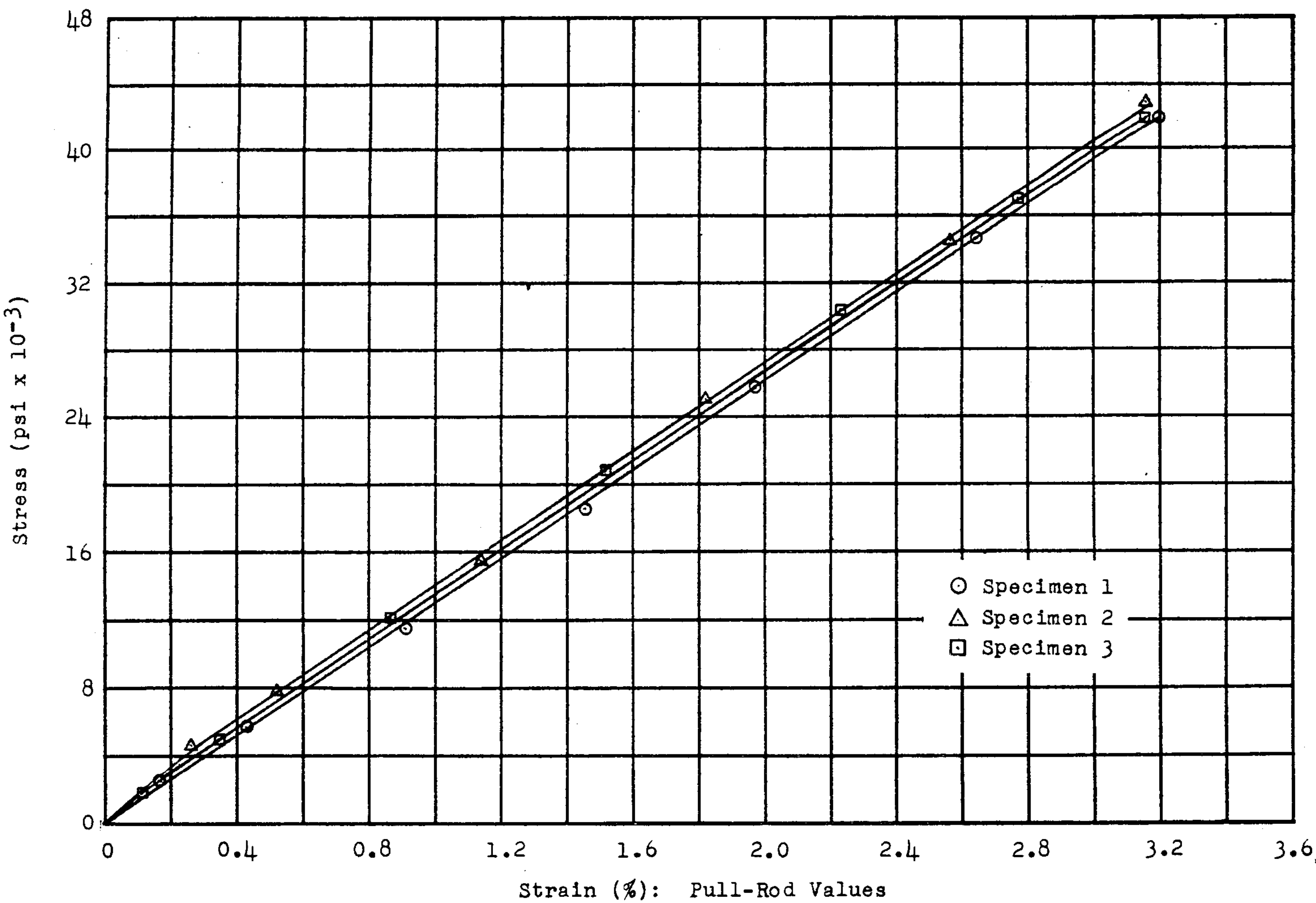

Figure E-10 Stress-Strain Curve (PRV) of CTL-91LD (Structural Laminate K) in LN_2: Preirradiation Control Run

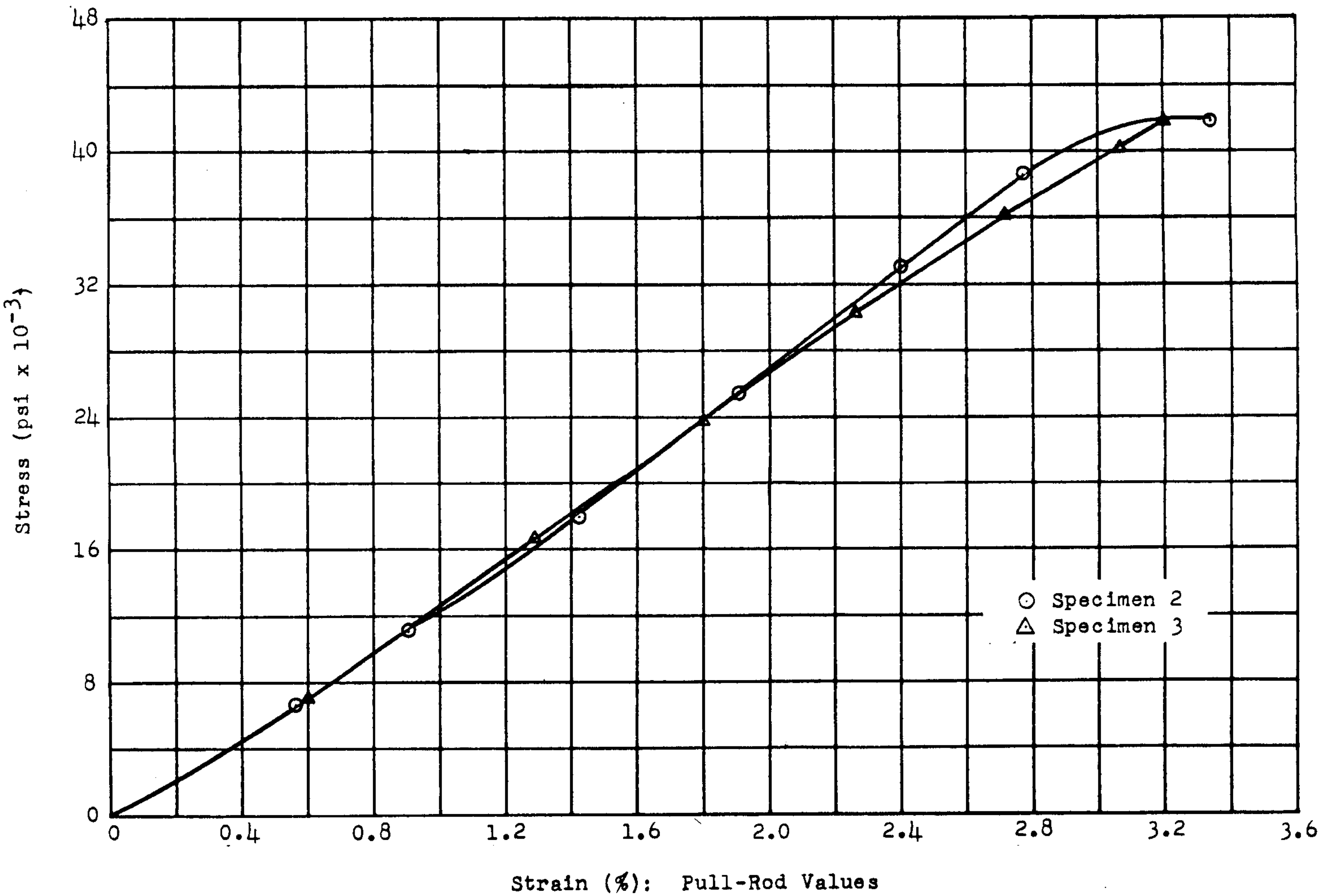

Figure E-11 Stress-Strain Curve (PRV) of CTL-91LD (Structural Laminate K) in LN_2: Low-Dose Exposure

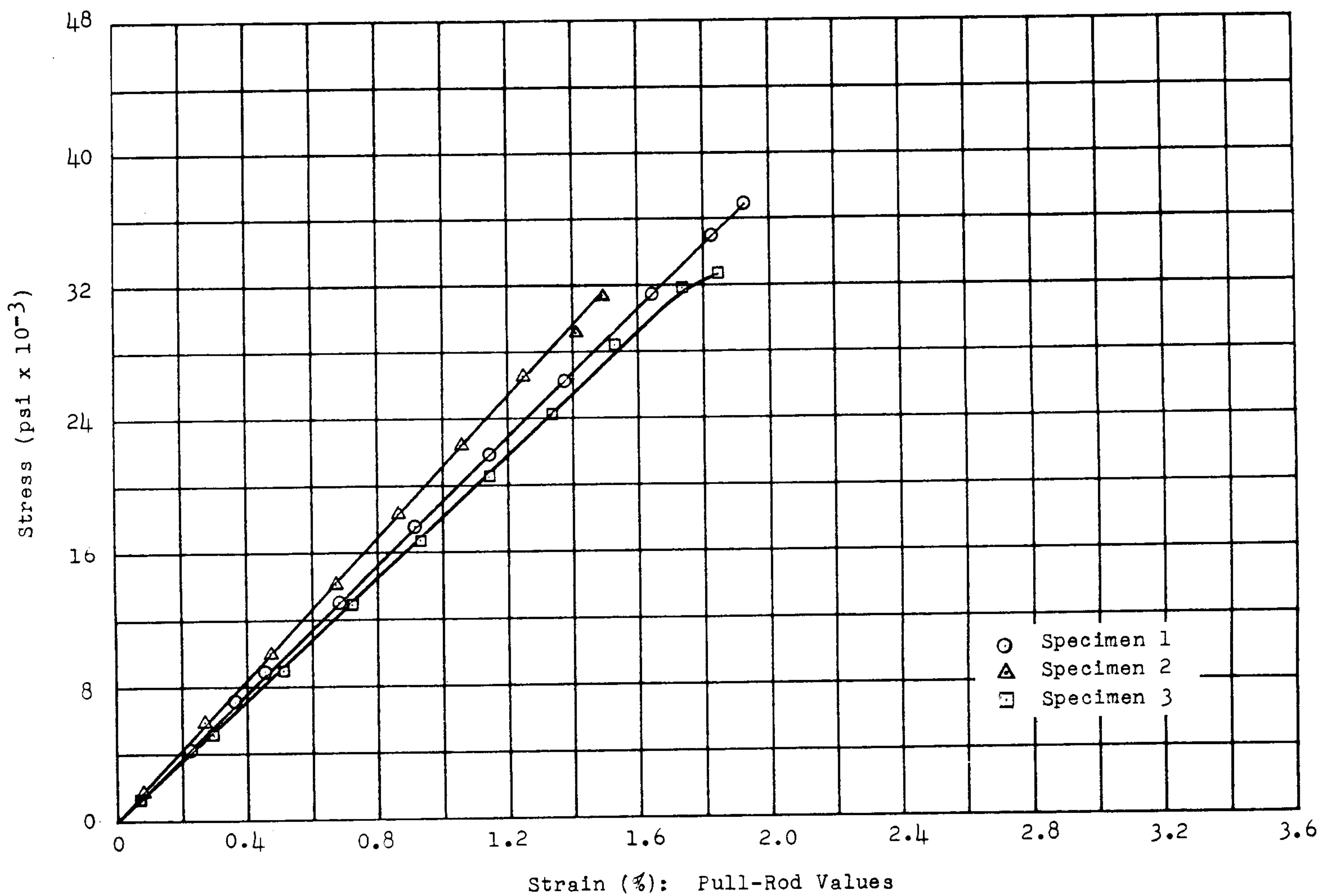

Figure E-12 Stress-Strain Curve (PRV) of CTL-91LD (Structural Laminate K) in LN_2: High-Dose Exposure

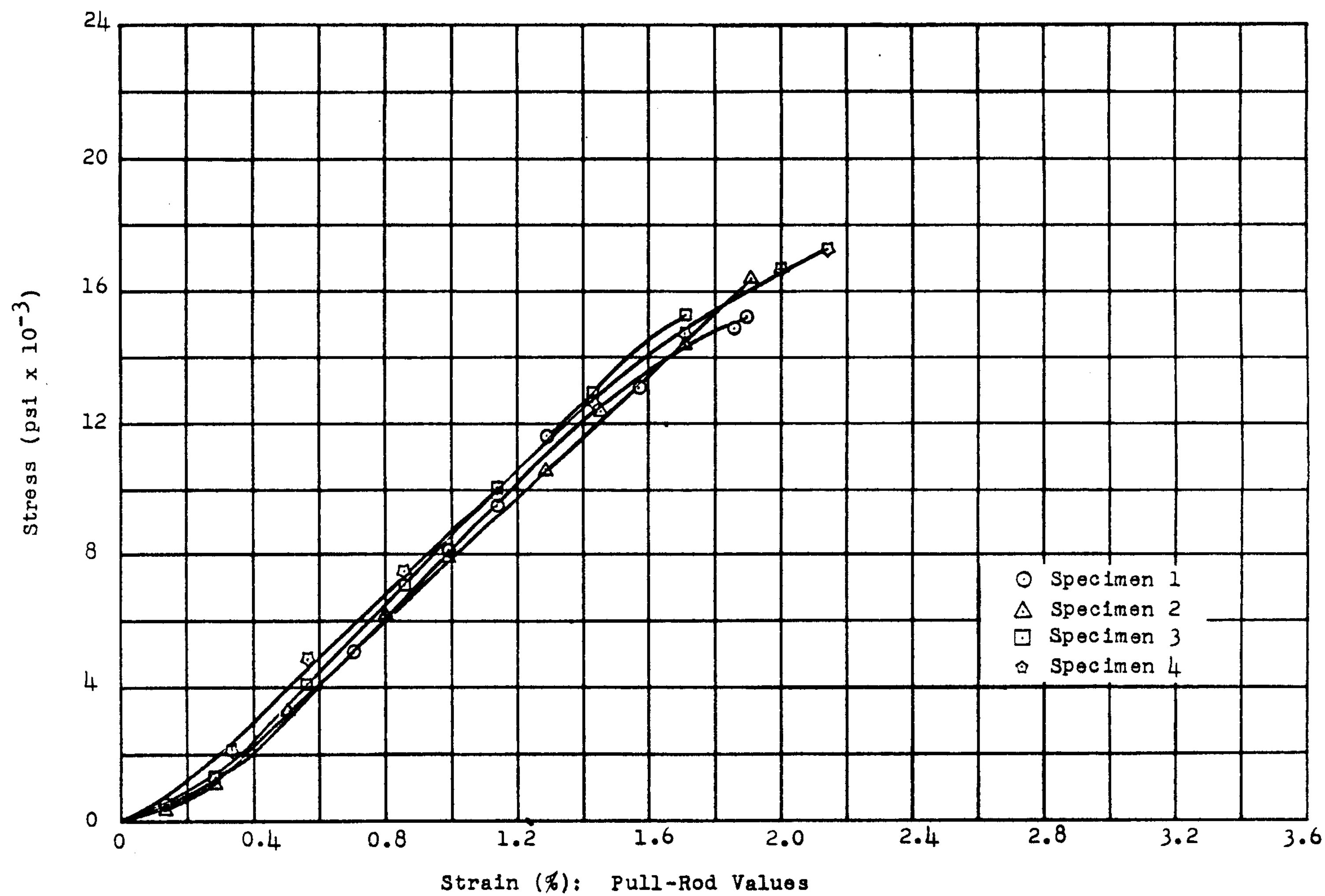

Figure E-13 Stress-Strain Curve (PRV) of Dow Corning 2104 (Structural Laminate L) at Ambient Temperature: Preirradiation Control Run

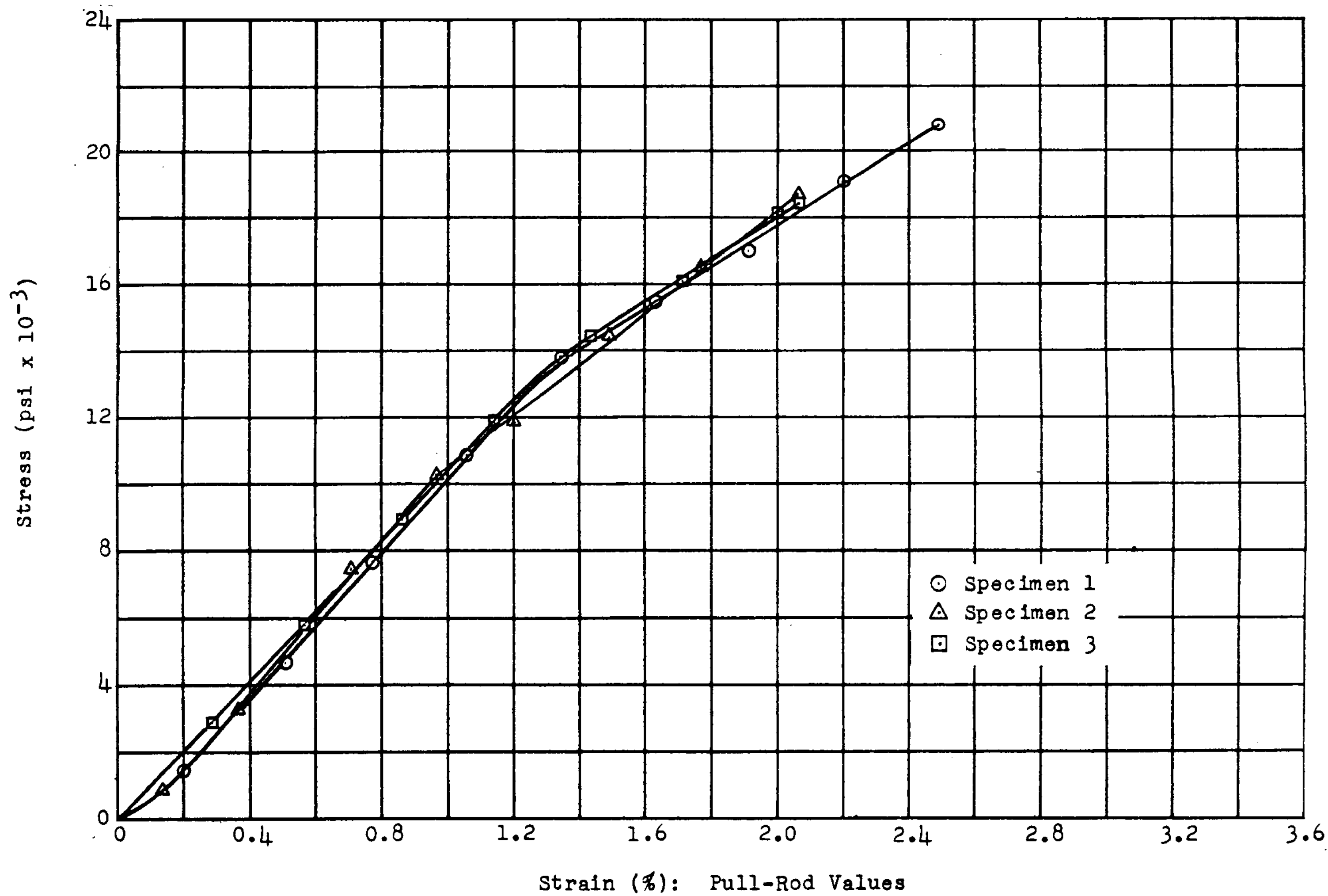

Figure E-14 Stress-Strain Curve (PRV) of Dow Corning 2104 (Structural Laminate L) at Ambient Temperature: Low-Dose Exposure

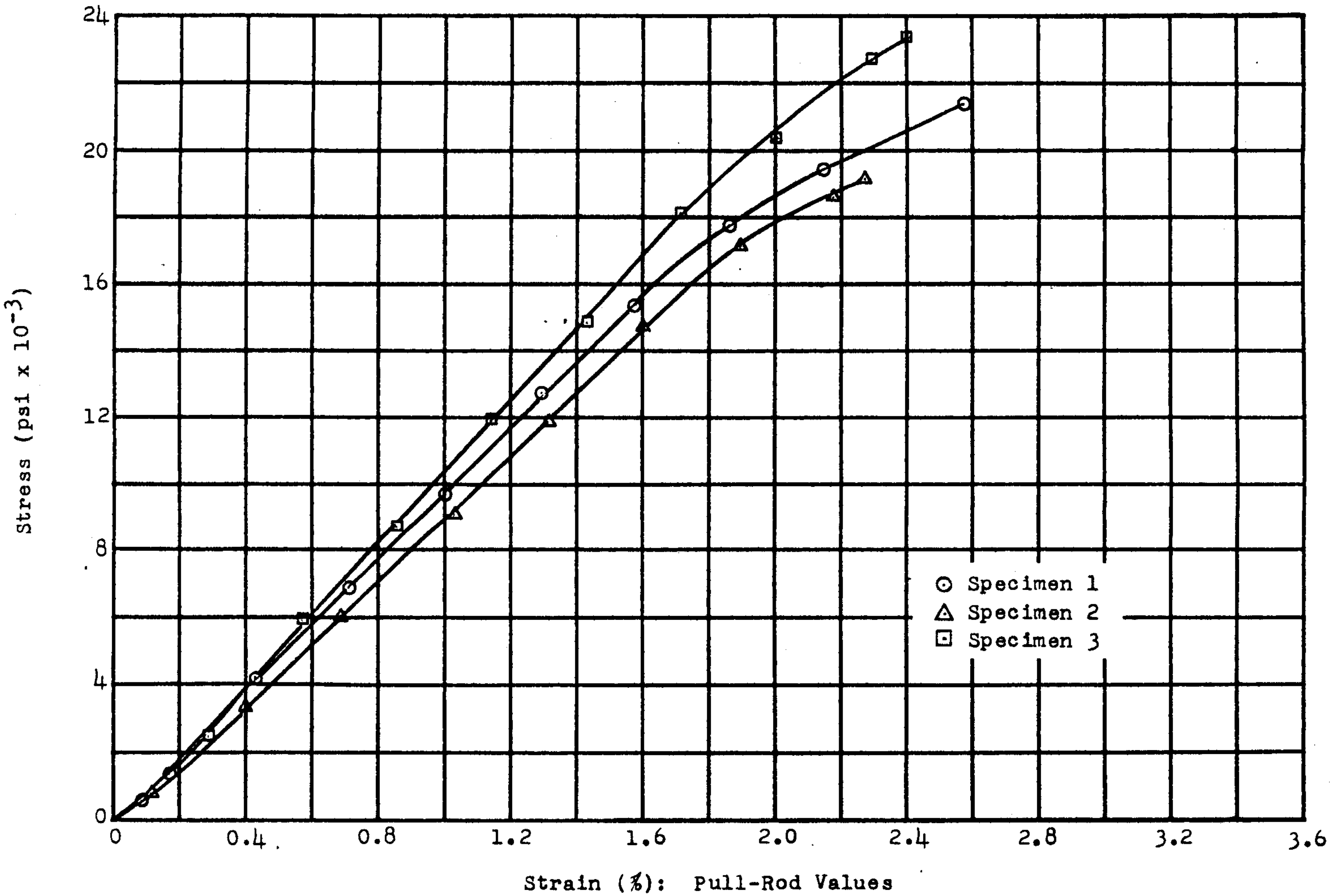

Figure E-15 Stress-Strain Curve (PRV) of Dow Corning 2104 (Structural Laminate L) at Ambient Temperature: High-Dose Exposure

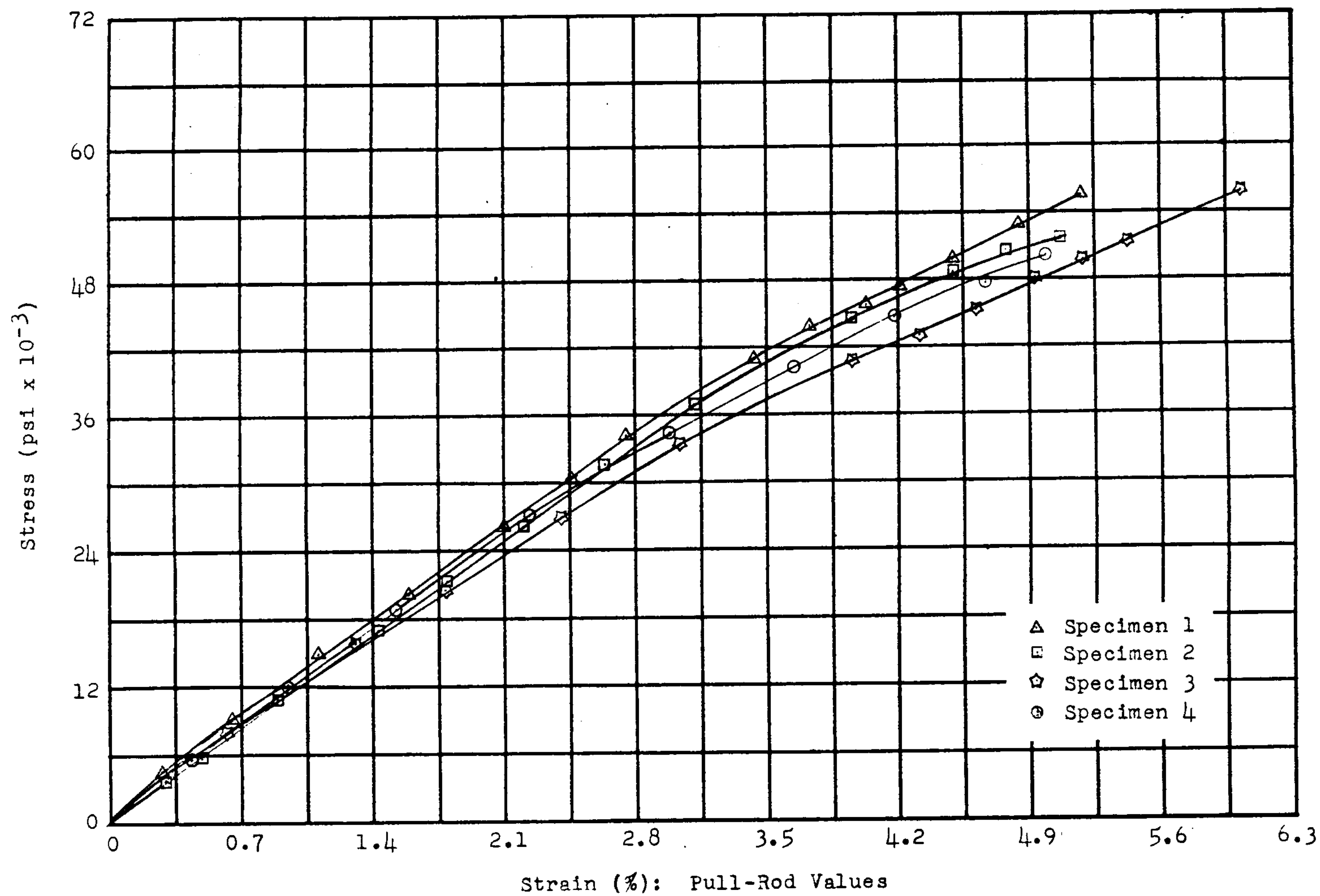

Figure E-16 Stress-Strain Curve (PRV) of Dow Corning 2104 (Structural Laminate L) in LN_2: Preirradiation Control Run

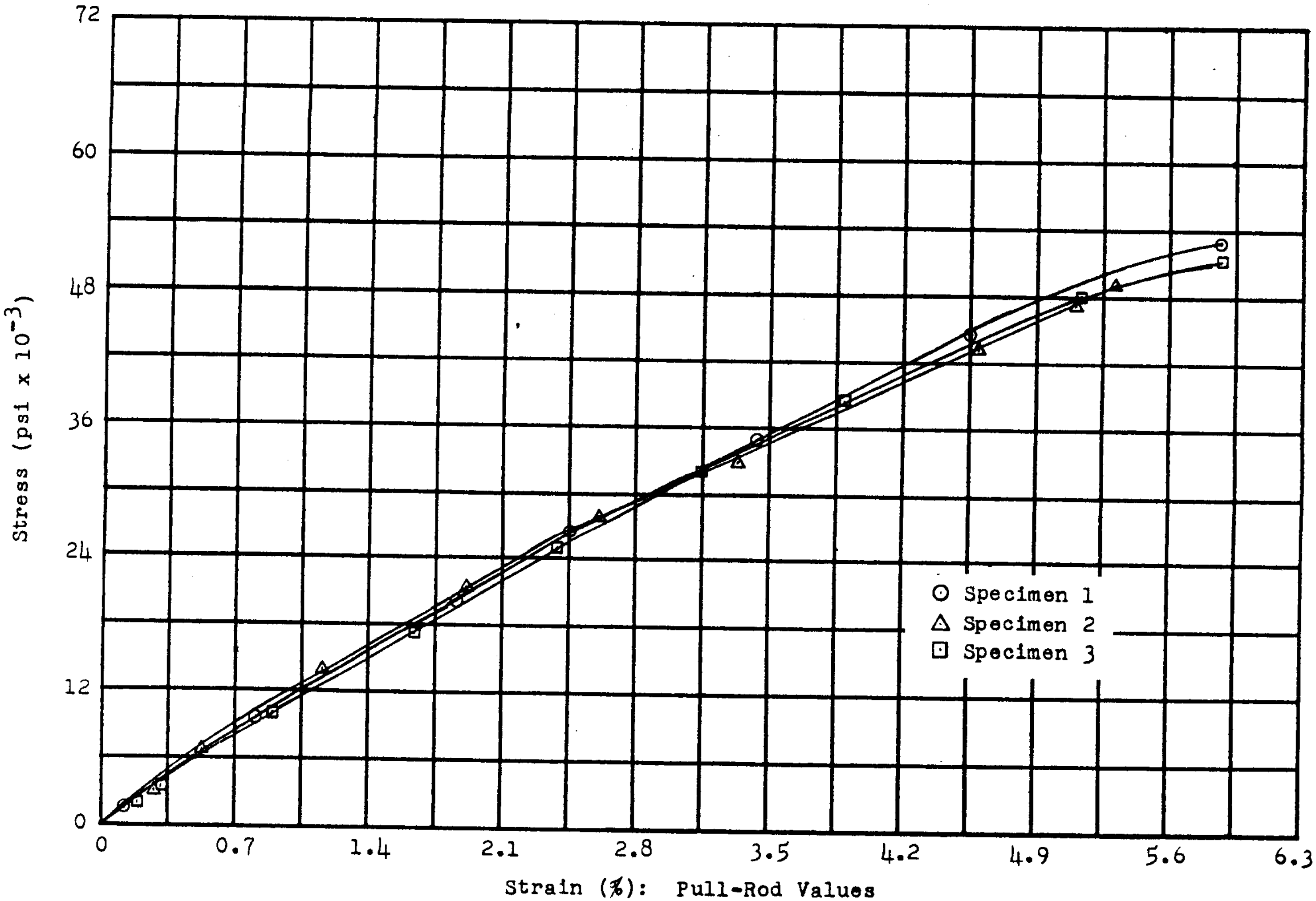

Figure E-17 Stress-Strain Curve (PRV) of Dow Corning 2104 (Structural Laminate L) in LN_2: Low-Dose Exposure

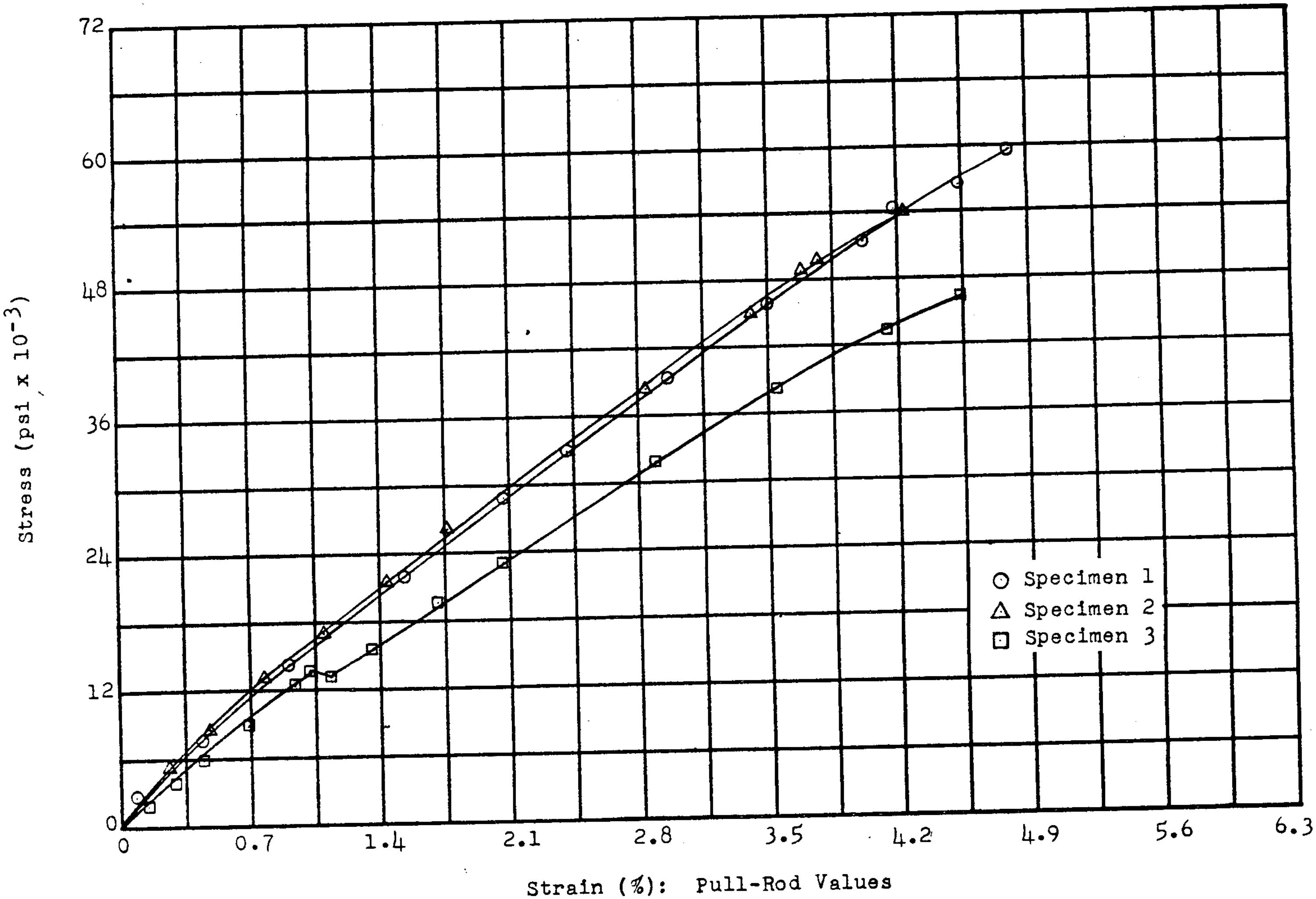

Figure E-18 Stress-Strain Curve (PRV) of Dow Corning 2104 (Structural Laminate L) in LN_2: High-Dose Exposure

APPENDIX F

STATISTICAL ANALYSIS OF SCOTCHWELD AF-40 AND AEROBOND 422J ADHESIVES

APPENDIX F

STATISTICAL ANALYSIS OF SCOTCHWELD AF-40 AND AEROBOND 422J ADHESIVES

This appendix contains the results of an analysis of tensile-shear-strength data for two lap-shear adhesive materials, classified as material A (Scotchweld AF-40) and material B (Aerobond 422J).

F-1 Basic Experimental Plan

The original experimental plan was based on a factorial arrangement of two factors to be investigated: temperature and radiation. Each factor was to be investigated at three levels, making a 3^2 factorial, or nine treatments. The nine treatments are shown in the following array:

Temperature	Radiation Exposure		
	d_o (zero)	d_1 (low)	d_2 (high)
t_o (Ambient-air)	$d_o t_o$	$d_1 t_o$	$d_2 t_o$
t_1 (LN_2)	$d_o t_1$	$d_1 t_1$	$d_2 t_1$
t_2 (LN_2)	$d_o t_2$	$d_1 t_2$	$d_2 t_2$

The physical limitations of the testing apparatus for one replication of the basic experiment allowed three samples per treatment. Five specimens could be cut from a single lap-shear sheet of material A and eight from material B. Since nine treatments were required for each material, it was impossible to run the experiment on one homogeneous group of specimens from one sheet. Therefore, the experiment was designed in a manner to remove from the analysis the effect of the differences between sheets.

Three of the five samples cut from each of nine sheets of material A were allocated to the main experiment. The two remaining samples from each sheet were set aside for testing in a "side experiment" to estimate an adjustment for normalizing the data to an overall sheet average. Since eight specimens could be cut from a single lap-shear sheet of material B, a different allocation of the samples was made that resulted in a slightly different experimental arrangement.

F-2 Analysis of Experimental Data

The above was the basic plan of the experiment. What follows is an analysis of the data from the experiment as it has progressed thus far.

The LH_2 set of treatments (d_ot_2, d_1t_2, and d_2t_2) has not been run; therefore, only a 3 x 2 factorial, or six treatments, has been completed. The 18 material A samples (two from each of nine sheets) were tested in February 1964. The control data (treatment t_od_o) for the main experiment were obtained in April 1963. The average control value of 5230 psi from the "side experiment" obtained in February 1964 differed from the April 1963 control average of 6220 psi by -990 psi. A 95% confidence interval on the difference is:

$$-990 \text{ psi} \pm 410 \text{ psi}.$$

This significant change seemed contradictory to other experiments conducted on similar materials, so that sources of possible biases were investigated. When no explanation was found, more samples of the remaining sheets were tested during March 1964. Table F-1 is a summary of the control data from the three tests.

Table F-1

Summary of Material A Control Data

	April 1963		February 1964		March 1964	
Sheet No.	Avg. Ten. Shear Strength (psi)	Number of Samples	Avg. Ten. Shear Strength (psi)	Number of Samples	Avg. Ten. Shear Strength (psi)	Number of Samples
1	6485	2	5060	1	-	-
2	-	-	6120	1	6640	2
3	-	-	5565	2	-	-
4	5590	1	5410	2	-	-
5	-	-	4955	2	-	-
6	-	-	5295	2	-	-
7	6310	1	4935	2	-	-
8	-	-	5445	2	-	-
9	-	-	5275	2	-	-
10	-	-	-	-	5812	5
11	-	-	-	-	6128	5
12	-	-	-	-	5112	5
13	-	-	4615	2	-	-
		4		18		17

This interval is calculated from the "between" and "within" components of variance. The estimates are given below:

$$\hat{\sigma}_{\text{between}} = 489$$

$$\hat{\sigma}_{\text{within}} = 371$$

$$\hat{\sigma}_{\text{combined}} = 598 \text{ (by analysis of variance method)}$$

$$\hat{\sigma}_{\text{combined}} = 591 \text{ (by range method)}$$

With a possible range in the control data of from 4100 psi to 7100 psi, it is difficult to detect small differences unless the differences are quite large compared to the variation or unless the number of samples per trial of the experiment is increased.

In the above case, the "between" component of variance is significantly larger than the "within" component, which indicates a highly variable bonding method. Bonding larger sheets so that more samples can be obtained from each sheet gives a more homogeneous group of material samples with which to conduct lap-shear experiments. This would decrease the combined variation, but only to the minimum limit of the "within" component.

On the basis of the test results, it was deemed impractical to make an adjustment of the data to an average sheet value. Therefore, the analysis was made by combining the "between" and "within" sheet variation which inflates the sampling error and lowers the sensitivity of the experiment.

The analysis deals with only a part of the whole experiment, since the LH_2 portion has not been run. The six treatments completed comprise three levels of dose - d_0, d_1, and d_2 in a progression of approximately 0, 1, and 6 - and two levels of temperature - t_0 (ambient) and t_1 (LN_2). Table F-2 is a summary of one replicate of the experiment of material A.

The main effect of temperature (T) occurs at two levels and the main effect of dose (D) occurs at three levels. The interaction between T and D can be obtained from the differences between the two rows of Table F-2.

Table F-2

Average* Values of Test Results for Material A
(psi)

	d_o	d_1	d_2	Totals
t_o	6220	6037	2620	14,877
t_1	3980	2707	1040	7,727
Totals	10,200	8744	3660	22,604
Average	5622	4372	1830	

*Average of 3 samples per treatment.

The effect of T is estimated separately at each level of D, the estimates being the difference between t_1 and t_o:

	d_o	d_1	d_2
$(t_1 - t_o)$	-2240	-3330	-1580

Any comparison among these three values is a measure of the effect of D on the response to T and is therefore a component of the interaction between T and D. Since we have a response to D at three levels of increasing dose, we may consider both the linear and the quadratic components of the response curve. Table F-3 is an analysis-of-variance summary of the data from Table F-2. This analysis considers the six treatment averages in some detail.

A pooled estimate of the sampling* error, σ_S^2 = 357,604, with 33 degrees of freedom was used to test the significance of the results of this one experiment.

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*This sampling error is not the experimental error required to estimate from the part to the whole. It can be used to test the significance of the results of this experiment. To estimate the experimental error would require a partial replication of the basic experiment under the same testing conditions.

Table F-3

Analysis of the Variance of the Average Tensile Shear Strength Values for Material A

Preliminary Analysis			
Source	Degrees of Freedom	Sums of Squares	Mean Squares
Temp.	1	8,162,001	8,162,001
Dose (γ)	2	11,392,336	5,196,168
TxD	2	810,521	405,260
Total	5	20,364,858	

Detailed Analysis		
Source	Degrees of Freedom	Sums of Squares or Mean Squares
T	1	8,162,001
D_{Linear}	1	11,392,128
$D_{Quadratic}$	1	207
TxD_{Linear}	1	273,241
$TxD_{Quadratic}$	1	537,280

In the preliminary analysis, the main effects of T and D are significant. The detailed analysis divides the D effect into its linear and quadratic components, both as a main-effect D and as an interaction TxD. The linear component, D_L, and T are significant at a confidence level of 99%; the D_Q is not significant. The interaction components TxD_L and TxD_Q are not significant. A generic plot of the data is illustrated in Figure F-1.

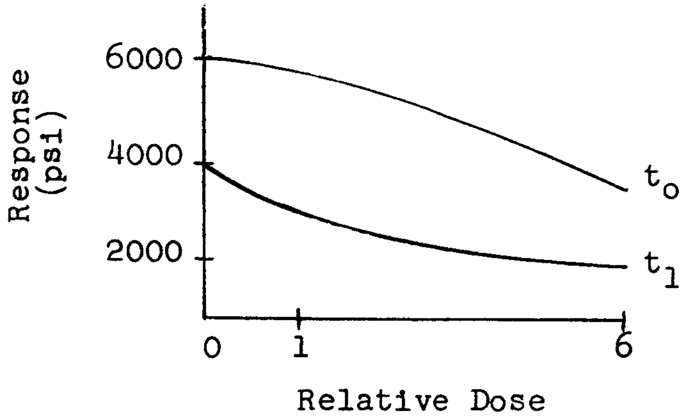

Figure F-1 Response Curves for Material A

A similar analysis was performed on the data for material B. The average control value of 2312 psi obtained in February 1964 differed from the average control value of 2540 psi obtained in April 1963 by -228 psi. A 95% confidence interval on the difference is:

$$-228 \text{ psi} \pm 126 \text{ psi}.$$

As with material A, material B was tested at two radiation doses (plus zero dose) and two temperatures, so that data for six treatments instead of nine were obtained. Thus, these data were analyzed under the same criteria as material A, that is, the "between" and "within" sheet variation were combined, inflating the sampling error with a corresponding loss in sensitivity.

The preliminary analysis of variance (not listed) of the data for material B showed a significant effect of temperature (T) at a 90% confidence level. Since the other effects were not significant, the linear and quadratic components subdivision was not considered. Although the data indicated a radiation effect at t_1d_2, the experiment was not sensitive enough to detect the change, if it existed. Figure F-2 is a generic plot of the data for each level of temperature, t_o and t_1, and for the three levels of dose.

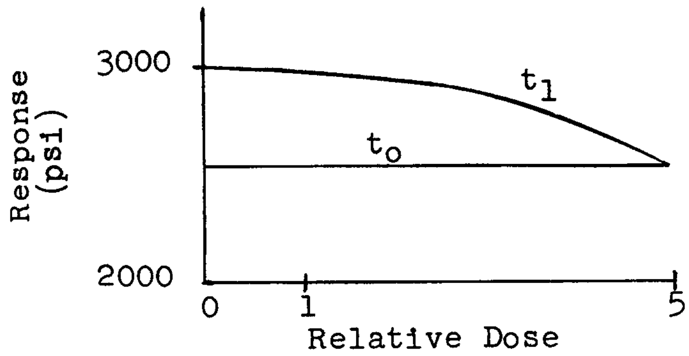

Figure F-2 Response Curves for Material B

F-3 <u>Results and Recommendations</u>

The results are summarized below:

1. Temperature (ambient to LN_2) and radiation decreased the tensile-shear-strength properties of the lap-shear samples of material A.

2. Temperature (ambient to LN_2) increased the tensile-shear-strength properties of the lap-shear samples of material B.

The following recommendations are made:

1. Some replication of the basic experimental plans should be conducted to guard against and/or discover chance occurrences of the type discussed above and to obtain a valid estimate of the experimental error.

2. The size of the bonded lap-shear sheets should be increased so that more samples per sheet can be obtained.

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